

ENGINEERING DRAWING

BY

HARVEY H. JORDAN, B.S.,

*Professor of General Engineering Drawing,
Head of the Department, and
Assistant Dean of the College of Engineering,
University of Illinois*

AND

RANDOLPH P. HOELSCHER, M.S.,

*Associate Professor of General Engineering Drawing,
University of Illinois*

SECOND EDITION

NEW YORK

JOHN WILEY & SONS, INC.

LONDON: CHAPMAN & HALL, LIMITED

1928

COPYRIGHT, 1923, 1928,
By
HARVEY H. JORDAN.

Printed in U. S. A.

5-29

Printing
T. H. GILSON CO.
BOSTON

Composition and Plates
TECHNICAL COMPOSITION CO.
CAMBRIDGE

Binding
STANHOPE BINDERY
BOSTON

PREFACE TO SECOND EDITION

No change from the first edition in the plan of organization of materials has been made in the second edition. Changes in the method of presenting certain topics and in content have been made as follows.

Chapter V has been entirely rewritten with the purpose of symplifying the presentation of the fundamental theory of orthographic projection. The figures are all new in this chapter and are done in pictorial drawing to a large extent. Chapter VI has also been revised on the same basis as Chapter V and expanded to include the second auxiliary plane of projection. Several working drawings have been added to Chapter VIII. The chapters on Lettering, Use of Instruments, and Chart and Diagram Drawing have been expanded considerably. Several new pages of tables and symbols on pipe layout work have been added to the appendix. In all, forty-two new figures have been added and sixty-one redrawn. All errors detected in the first edition have been eliminated.

The authors gratefully acknowledge the constructive criticisms offered by the users of the text.

URBANA, ILLINOIS,
May, 1928.

PREFACE TO FIRST EDITION

An author's justification for offering to the public a new text book on any subject must find its root in one or both of two purposes — either to present the discovery of new facts and the development of new theories, or to reclassify and revitalize already known facts and theories in a manner better calculated to meet the changing needs of the times in which he lives.

The authors of this text on Engineering Drawing present it to the Engineering profession and others desirous of perfecting themselves in the technics of the graphical language, with no claim, thereby, to having added to the common stock of the world's knowledge. Rather, it is with the hope and aspiration of putting many closely related, though sometimes isolated, bits of knowledge into a more complete and harmonious whole than has hitherto been done, that the work has been undertaken and accomplished. The success of their labors must depend largely upon how well they have wrought in this respect.

It has been well said that Drawing is simply the expression of the geometrical concepts of man in a graphical language. To the understanding of its fundamental grammar and composition, therefore, must be added the manual skill necessary to its successful execution. The authors have been keenly mindful of these premises and, although subordinating perfect execution to thorough understanding in emphasizing fundamental phases of the various topics, they have attempted to treat the subject-matter from the point of view of users and teachers of a universal language.

Five kinds of materials have been recognized as proper to be included in this book: (1) Elementary fundamental theories and concepts underlying all forms of Drawing; (2) Illustrations explaining the theory and demonstrating proper modes of execution; (3) Complex but related principles; (4) Encyclopedic or handbook materials, — sometimes called commercial practices; and (5) Problems.

Materials in the first and second divisions have been developed in a consistent and orderly manner through chapter arrangement.

These are in themselves complete units or entities. Those using the text will find them not too long, but self-contained and comprehensive. Those materials falling in the third division have been segregated into subsections in the chapters in which they naturally belong and are thus kept from obscuring and confusing the objective things on which a student's attention must be focused in the main section of the chapter. Materials falling into the fourth group have been collected into the Appendix and indexed; or, in some cases, they have been put into the subsection of a related chapter. Problems have been omitted altogether, on the ground that they destroy the local color and initiative of the department of Drawing using them, and soon become a stereotyped list of exercises planned by a person or persons in whom the student has no interest, and which have been solved and put on file by scores of his fellow students before him. It is intended that a book of such exercises for instructor's use and guidance shall be prepared later, as the demands may become great enough to warrant such compilation.

Part I deals with the four fundamental kinds of projections and their applications in mechanical and freehand drawing. Chapters on Shop Terms and Processes, Sketching, and Reproduction of Drawings are included at the proper coördinating places. This part of the text should be considered the minimum content of any thorough course on Drawing.

Part II treats of the applications of the principles laid down in Part I to the various fields of Drafting, such as Architectural, Structural, Map, Patent Office, etc. A comprehensive chapter embodying the fundamental and underlying principles of Graphic Methods, hitherto omitted from Drawing texts, is considered opportune and in its proper setting.

The Appendix contains symbols and conventions in various fields of Drawing, geometrical constructions, and tables of data generally needed by students in the drawing room or office.

Grateful acknowledgment is made to those members of the Department of General Engineering Drawing at the University of Illinois who have made helpful suggestions during the preparation of the manuscript, and especially to Professor J. K. McNeely who has so effectively read the text material and offered helpful criticism.

The authors also express sincere appreciation and acknowledgment to the Department of Architecture at the University and to

several individuals and commercial companies, for permission to use drawings and cuts and in some cases text material, which have added greatly to the value of the work. Reference is made to this assistance at the proper places in the body of the text material.

URBANA, ILLINOIS,
May, 1923.

CONTENTS

	PAGE
PREFACE.....	iii
CHAPTER I. — INTRODUCTORY.....	1
Drawing a graphical language — Two main divisions: mechanical and freehand — Subdivision into Machine, Structural, Architectural, etc. — Drafting a means to an end — Method of Study.	
CHAPTER II. — LETTERING.....	4
Reinhardt engineering style — Original and modified alphabets — Upper and lower case letters — Elements — Composition of stem and oval — Slope — Guide Lines — Principles of stability and balance — Compressed and expanded alphabets — Lettering tools — Mechanical letters — Unit of measure — Useful alphabets — Bibliography.	
CHAPTER III. — TITLES.....	29
Necessity of titles — Design — Location on sheet — Size — Size of letters — Prominence of parts — Balance — Finish and embellishments — Printed titles.	
CHAPTER IV. — USE AND CARE OF INSTRUMENTS.....	36
The draftsman's "kit" — Pencils and Pens — Erasers — T-square — Triangles — Papers — Scales — Drawing instruments — Irregular Curves.	
CHAPTER V. — ORTHOGRAPHIC PROJECTION.....	51
Elements of Projection — Theory of Projection — Projecting Lines — Point of Sight — Planes of Projection — Rotation of Coördinate Planes — Dihedral Angles — Choice of Quadrants — Position of Object in Space — Invisible Lines.	
CHAPTER VI. — AUXILIARY AND SECTION PLANES.....	63
Need of additional planes of projection — Auxiliary views: method of construction, location on sheet, and dimensioning — Section planes — Full and half sections — Section lining — Revolved or interpolated sections — Removed sectional views — Indicating and locating views — Broken sections.	
CHAPTER VII, SECTION 1. — WORKING DRAWINGS.....	76
Definition — Division into assembly and detail drawings — Character and uses of assembly drawings — Classification of detail draw-	

	PAGE
ings — Important considerations in making working (shop) drawings: selection of paper, title, and scales; arrangement of views; sectional views; order of pencilling and inking; conventional lines and symbols; rules for dimensioning; checking, revising, tracing — Bill of materials — Blueprinting — Practical methods.	
SECTION 2. — Variations in dimensioning: one way, solid line, omission of unit signs — Allowances and limits — Metric system — True length of lines — Intersection of common surfaces — Fillets and rounded corners — Development of surfaces — Shade lining — Line shading — Partial sectioning — Sectioning, odd numbered axes of symmetry.	
CHAPTER VIII. — FASTENERS	114
Division into two classes — Bolts and screws classified and defined — Thread forms and terms — Cutting threads — Representation of threads in bolts and screws — Dimensioning bolts and screws — Pipe threads — Rivets — Keys and spline fittings.	
CHAPTER IX. — SHOP TERMS AND PROCESSES	130
Relation of shops and drafting room — Pattern Shop: pattern maker's rule, draft and parting lines, fillet, core, core box, etc. — Foundry — Forge Shop: drop forging, tempering, annealing, etc. — Machine Shop: drilling, turning, grinding, planing, milling, broaching, etc. — Jigs and Fixtures.	
CHAPTER X. — PICTORIAL DRAWING	139
Definitions — Classifications — Uses — Methods of drawing.	
CHAPTER XI, SECTION 1. — ISOMETRIC PROJECTION	142
Definition and terms — Scale — Drawing of solids and plane figures — Dimensioning — Sections — Screw threads — Variations in position of directrices.	
SECTION 2. — General axonometric projection — Isometric, dimetric, and trimetric projections compared.	
CHAPTER XII, SECTION 1. — OBLIQUE PROJECTION	156
Definition — Cavalier Projection — Solid and plane figures — Cabinet drawing — General oblique drawing — Dimensioning — Sectioning — Threads — Advantages.	
SECTION 2. — Variations of oblique projection — Applications in mineralogy and crystallography — Six principal sets of axes — Bibliography.	
CHAPTER XIII. — PERSPECTIVE	168
Definition — Point of sight — Picture plane — Perspective of a point — Vanishing points — Perspective of a solid — Parallel per-	

spective — Angular perspective: visual ray method and line method
— Measurements — General methods — Bibliography.

CHAPTER XIV. — SKETCHING 182

Distinction between technical and artistic sketching — Use of sketches — Kinds of projections used — Sketch stroke — Rules for proportioning — Sketch materials — Dimensioning — Short cuts and empirical variations.

CHAPTER XV. — REPRODUCTION OF ENGINEERING DRAWINGS 188

Need of multiple prints — Blue print process: frame, exposure of print, washing, intensifying, sensitizers, chemistry of process, etc. — Brown print process — Blue line process — Photographic reproduction — Hectograph — Line etchings — Drawings for etchings — Half tone process — Wax process — Lithographic process — Ozalid process.

CHAPTER XVI. — DESIGN 199

Distinction between drafting and design — Technical design — Empirical design: clearance, rivet spacing, shop methods, building details, etc.

CHAPTER XVII. — CHART AND DIAGRAM DRAWING 202

Universal use of charts and diagrams — Drafting problems involved — Definitions and classifications — Plane curves: coördinate papers; selecting, locating, and marking axes; slope of curve; drawing the curve in accordance with its use; Joint Committee standards; technique; titles and legends — Line diagrams (barographs) — Rules governing construction of barographs — Area and volume diagrams — Objections to area and volume diagrams — Map and distribution diagrams — Graphic statics and vector diagrams — Nomographs — Three dimensional charts — Bibliography.

CHAPTER XVIII. — MAP DRAWING 229

Map projections — Classification: geographic, topographic, cadastral, engineering — Selection of scales; size, purpose, cost, length of use of drawing — Symbols: size and color, spacing, position on sheet, and how to draw symbols — Special symbols — Methods of plotting a traverse: protractor and scale, tangent method, and coördinate method — Representation of elevation: hachures, contour lines, rules for contour work — Profiles on straight and curved lines — Profile paper — Map lettering — Titles — Bibliography.

CHAPTER XIX. — ARCHITECTURAL DRAWING 251

Kinds of views used — Classification: working drawings, preliminary and display sketches — Preliminary drawings — Display drawings — Working drawings: plot and floor plans, elevations, sections, details, dimensioning, notes, specifications, symbols, titles, technique, lettering — Bibliography.

CHAPTER XX. — STRUCTURAL DRAWING.....	PAGE 271
Scope — Definition of terms — Set of plans: general plan, stress diagram, shop drawing, foundation plan, erection diagrams, false-work plan, bill of materials, rivet list, list of drawings — Shop drawings: number and location of views, bottom view, details, symmetrical members, sectional views — Standard details: structural shapes, gage lines, rivet sizes and spacing — Detailing a truss — Layout of joint — Scales — Dimensions — Notes — Titles — Marking pieces — Conventional symbols — Bibliography.	
CHAPTER XXI. — PATENT OFFICE DRAWING.....	291
Character of drawings — Application for Patents: specifications, drawings, rules of practice, symbols.	
APPENDIX.....	299
Geometrical construction of plane figures: circles tangent to lines, lines tangent to any curve, conic sections, cycloids, etc. — Symbols: map, metals, electrical, decimal equivalents, heating and ventilating, etc. — Tables: bolts and screws, wire and plate gages, rivet spacing, metric equivalents, pipe layouts, natural trigonometric functions.	
PROBLEMS.....	344

ENGINEERING DRAWING

PART I

CHAPTER I

INTRODUCTORY

In designing machines, factories, dams, railroads, and other structures for man's use, the engineer must first form a clear mental picture of the thing to be built, before any work can be done on its actual construction. He must then convey his picture to the constructor, furnishing him data which will give the exact sizes of all parts, the kind of materials of which they are to be made, the positions they are to occupy with respect to each other in the completed machine or structure, the finish and exactness required in their construction, and many other bits of information which are of importance to the builder in his work.

Only two agencies exist by which the ideas of the designer may be transmitted to the constructor without the use of models, — the first and older being that of written or oral language, the second, that of drawings or pictures. A little reflection serves to convince one that it would be an impossible task to describe in oral or written language such a simple machine as a gas engine, for instance, with dimensions and data sufficient to allow of its construction in pattern, foundry, and machine shop. Many printed pages would be consumed in the effort, and few workmen would be able to form from such data any conception of the machine desired to be built.

It is on account of this inability of the written and oral language to convey the designs of the engineer to his fellowmen that he has devised for his use another language called the Graphical Language, or Drawing. This graphical language, although quite unlike our everyday language in some respects, has, however, many points of similarity with it; and these likenesses should always be kept in

mind when learning this newer medium for conveying ideas. Before studying these points of resemblance in detail, the beginner should learn thoroughly a few definitions of terms generally used among draftsmen and engineers in describing and classifying various kinds of drawings.

Two main divisions of Engineering Drawing are usually recognized, namely, Mechanical Drawing and Freehand Drawing. Much the same differences exist between them as between the type-written sheet and one done in longhand. Under the title of Mechanical Drawing is included all drawings made with the use of instruments of precision, commonly called the "Draftsman's Kit." In making such drawings, not only does the draftsman have to master the principles of the language itself, but he must also become wholly proficient in the use of the tools with which he writes the language. When the graphical language is written without the aid of instruments of precision and with only pencils or pens for tools, the drawings are called Freehand Drawings, or Sketches.

The use of Mechanical Drawing as defined above is limited almost exclusively to engineers and architects, while Freehand Drawing is used by the artist as well as by the engineer. The artist, however, endeavors to show only the form, proportions, texture of materials, and the effect of light upon an object by means of shades and shadows. The engineer must not only show form, proportions, and the nature of the materials, but he must give the exact sizes of the parts, their finish, and the clearances to be maintained. Ordinarily, he has nothing to do with shades and shadows.

We are chiefly concerned in this text with Mechanical Drawing, and Freehand Drawing as used by the engineer.

Each of the two kinds of drawing described above is further classified as *Machine*, *Structural*, *Topographical*, etc., depending upon the object represented, in much the same way as the written language is divided into the four major forms of composition, namely, description, narration, exposition, and argumentation. As in the various forms of written composition, so is it true in the different kinds of drawing, that the fundamental principles of the language are the same in all cases. We are interested here more with the **fundamentals**, or **grammar**, of the language itself than with the **styles** it may assume in the hands of individual users.

It will be seen, then, that the importance of the **engineer's** learning how to read and write this most useful and forceful language can hardly be overemphasized. Our object in this text is to study

this graphical language in order that we may use it in engineering practice in the same way as an author uses the written language in the practice of his profession. In the words of a recent writer on drawing,¹ "We must know the alphabet, the grammar and the rhetoric, and be familiar with the idioms, the accepted conventions, and the abbreviations." It should be noted in passing that this graphical language is the only language in existence which is understood and written readily in all countries where scientific knowledge is applied at all to the purposes of man.

Always it must be understood that our study of this most important tool of all those in the engineer's possession is not in itself the end or goal to be reached, but is rather to be considered as a means to an end; that end is the ability to do engineering work and converse in the engineer's language. Few men attain distinction as **draftsmen**, just as few men become authors or poets, but every engineering student should strive to master the technics of graphical expression, not with the hope of becoming a draftsman, but rather with the determination of becoming an engineer. It can hardly be said that there is a *profession of drafting*, since most draftsmen are engineers in the true sense of the word, and they apply their knowledge of drawing in the same way and for the same purposes as they do their knowledge of mathematics.

In studying the text, a student should read a paragraph or a group of related paragraphs and then see if he can restate the main points correctly in his own terms without reference to the text. If this cannot be done, he should reread the material and underscore lightly those phrases and sentences that give the gist of the matter and then again attempt to state the facts. Repeat, if necessary. When an entire chapter or assignment has been covered in this way, a comprehensive outline of the principal points should be written without reference to the text. The outline need not be filled in with much detail but enough should be jotted down to permit a careful check against the book. Omitted portions should be added and the whole reviewed to get the proper relations of the parts.

¹ *Engineering Drawing* by Professor Thomas E. French.

CHAPTER II

LETTERING

SECTION 1

The first essential prerequisite to the successful use of the graphical language is a complete mastery of the art of lettering. Every drawing must have dimensions, a title, and notes placed upon it before it becomes workable, — has life, as it were. Besides making it workable, the lettering put upon a drawing will either embellish it or ruin it, depending upon the skill of the draftsman in making the simple style of letter and figure which the engineering profession has approved.

Nearly all engineers, except the architectural engineer, use a style of letter called the Reinhardt vertical or slant letter. Mr. Reinhardt was for many years engineering draftsman and illustrator for the Engineering News, and evolved from his experience a very simple kind of lettering which, in honor of his genius, has been called the *Reinhardt style* by common consent of the engineering profession. Any student can learn to do this kind of lettering well, with a little careful study of its component parts and diligent practice in its proper execution.

STYLE IN LETTERING. — In referring to any piece of lettering as having a certain *style*, we mean to convey three principal ideas either by direct statement or by implication. The first is that of the *original or basic form and character* of the type of letter used; the second is that of the *modification or change* from the original form; and the third is that of the *direction of stroke or slope* used in making the individual letters. In the example shown in Fig. 1, the word "Gothic" indicates the basic form of the alphabet; the words "single stroke" give the information that the width of the components of the letters is to equal the width of a single stroke of the pen; and the word "vertical" tells us that the *stem* strokes are to be straight up and down the sheet in such letters as H, I, M, N, L, etc. These three factors must always be taken into account when

designating the style of any alphabet or job of lettering. Each is discussed briefly in the following paragraphs.

Original Alphabets. — The oldest type of letter bearing close resemblance to the kind now used by engineers is the Roman. It was derived from the Greek, which in turn was adapted from the Phoenician. It is well to remember that the Roman alphabet, in almost the same form as we now have it, came into existence twenty-five hundred years ago, and it undoubtedly will continue to be the most generally used alphabet in the world. The original form of this alphabet is referred to as the Old Roman. A complete alphabet of Old Roman is shown in Section 2 of this chapter. This alphabet is still used by architects, although many modifications have been devised.

Modified Alphabets. — It is only natural that the original alphabets should have undergone considerable modification in the interest of simplicity of design or to suit the fancy of some ingenious printer. Thus we find that considerable change in the first Roman alphabet has been made by those who have been users of it during the last twenty centuries, until a very definite and beautiful style, called the Modern Roman, has been evolved. In Section 2 of this chapter the Modern Roman alphabet is shown in contrast with the Original Roman. The former is still much used in engineering work, particularly where an excellent and striking appearance is desired, for instance, in a title or inscription. Its more standardized and simplified appearance, as well as its inherent beauty and stateliness, should be studied carefully.

Another one of the older modified forms which is much simpler in its construction, although not so beautiful as the Roman, is called the Gothic. This style is plain and severe, being stripped of all serifs. All the components of the letters are of the same weight, and hence are more easily made. This alphabet is shown in Section 2. It may be built up to any width and height, or the outlines of the letters may be stroked in and the open spaces filled with brush or pen.

It was this very fact of modification and simplification which caused the Reinhardt style to be so instantly accepted for engineering use. This modification of the Gothic, — originally derived



FIG. 1. Single stroke vertical Gothic letters.

from the Roman — lends itself readily to rapid construction and is very easy to read. It is made with a single stroke of the pen for each component part and is therefore called the Single Stroke Gothic. See Fig. 1.

Slope. — To completely indicate the style of a letter we must mention the direction of stroke, whether it be vertical or slanting. Vertical lettering is spoken of by some as “upright” lettering; as its name suggests, the strokes are perpendicular to the axis of the line of lettering. In slant lettering many angles of slope are used, and although good appearance may be obtained at any angle between 65 and 75 degrees, consideration of best effect dictates adherence to a fairly well-determined standard of 72 degrees from the horizontal.

Bearing the above observations in mind, we shall direct our attention to the study of those styles of lettering known as the *Reinhardt slant and vertical styles*. Such modifications as are thought to improve upon the original forms will be suggested, and general rules for the execution of these styles will be given.

UPPER AND LOWER CASE LETTERS. — In any style of lettering, two kinds of alphabets are universally used. The one is known as the Large Letters or Capitals, the other is known as the Small Letters. On account of the custom of the early printers of keeping the capitals in the upper part of their case and the small letters in the lower part of the same case, they came to be known as the Upper and Lower Case letters, respectively. These dual names for each alphabet are still commonly used and must be understood by the engineer who generally prefers, however, the names given first.

Whenever the capitals, or upper case letters, are used in the same words or sentences with the small, or lower case letters, a fixed ratio between their heights is always adhered to. The long strokes in the small letters are made equal to the height of the capitals, with the single exception of *t*, which is just a bit shorter than other strokes of its class. The bodies of the small letters, on the other hand, are two-thirds the height of the capitals. This ratio is always maintained by ruling guide lines, either with a scale and straight edge or with a lettering triangle. When tracing a drawing, the guide lines should be ruled again on the tracing cloth before attempting to trace the lettering. This practice should be followed strictly even in lettering a single word. The phrase “height of the letters” means the height of the capitals or long stems.

ELEMENTS.—The Reinhardt alphabet is composed of two simple elements, with slight variations in a few letters in the interest of better appearance or on account of some peculiarity of an individual letter. The first of these elements is called the *Stem* of the letter and is made with a single downward stroke of the pen. The second element is called the *Oval* of the letter and is made with one or two strokes of the pen, depending upon the size being used.

A B C D E F G H I J K L M N O
P Q R S T U V W X Y Z &
a b c d e f g h i j k l m n o p q r s t u v w x y y z

FIG. 2. Engineer's vertical single stroke alphabet.

When one has mastered these two simple elements and has learned to combine them properly, he is able to produce satisfactorily the engineer's alphabets shown in Figs. 2 and 3.

Stems.—As indicated above, the stems of letters are those single straight line strokes which form a part of more than four-fifths of all the letters in the alphabet. It is the direction of the

A B C D E F G H I J K L M N O P
Q R S T U V W X Y Z &
a b c d e f g h i j k l m n o p q r s t u v w x y y z

FIG. 3. Engineer's slant single stroke alphabet.

stems of such letters as *H*, *M*, and *N* which determines the *slant* of the letters. In Fig. 2 the vertical alphabet is shown. In Fig. 3 a slope of 72 degrees, recognized as the standard for slant lettering, has been used.

It should be noted that all stems are of the same vertical height in the capitals, while in the small letters two heights are used. The shorter stems are two-thirds the height of the longer ones, which we remember is the exact ratio between the capitals and the small letters. It has always been customary to make the small *t* a little shorter than the long stems, thus automatically forcing the crossing bar to the level of the tops of the ovals and thereby making a

better spacing appearance than would be the case if the stem were full length and the bar raised. Several straight line strokes occur in some of the letters, such as the horizontals in *A*, *E*, *F*, and *H*, as well as the inclined strokes in *K* and *Y*, which are not classed as stems but which need no comment other than to direct attention to their off-center location, — the bar in *A*, for instance, being below, and the bar in *H* being above the center line. Further mention is made of these variations in a later paragraph.

The only requisites of well-made stems are (1) uniform weight of strokes throughout their entire length, (2) perfect straightness

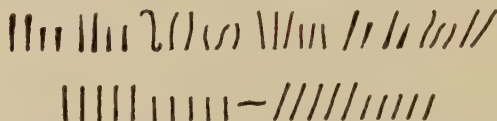


FIG. 4. Incorrect and correct stem strokes.

of outline without curls either at the beginning or end of the stroke, and (3) uniformity of slant in all the letters. Much depends upon the ink and pen used in obtaining the proper weight of line, but straightness and uniformity of slant are mere matters of critical eye and hand practice. Good and poor results are shown in Fig. 4.

Ovals. — The second element in lettering is a perfect ellipse, with a fairly well-determined ratio existing between its major and

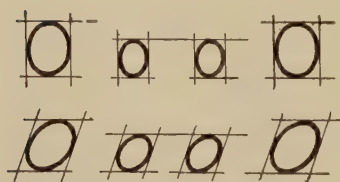


FIG. 5. Correct oval stroke.

minor axes. In Fig. 5, the horizontal width of the parallelogram enclosing the ellipse is made five-sixths its height. The ellipse touches the four sides of the parallelogram exactly at their mid-points. These proportions give what is termed the *normal* or *standard* vertical or slant oval,

and when combined properly with the stem produces the Normal or Standard Alphabet. It must not be understood that the five-sixths ratio is a hard and fast requirement, although it furnishes a good working basis. In any case, however, the horizontal width of the oval should be slightly less than the height, for normal letters.

In executing the oval it will be found helpful to begin with rather large sizes, say three-fourths of an inch high. The contour of the

ellipse should be sketched in with full sweeping strokes, an attempt being made to secure the perfect shape so essential to a graceful style. As the smaller sizes are chosen, the sketch stroke should be abandoned and two smooth strokes used. Finally, with heights of one-eighth inch or less, a single stroke may be adopted. Figure 6 illustrates the procedure to be followed.

COMBINATION OF STEM AND OVAL. — When one has mastered the technique of the individual elements, it becomes a simple task

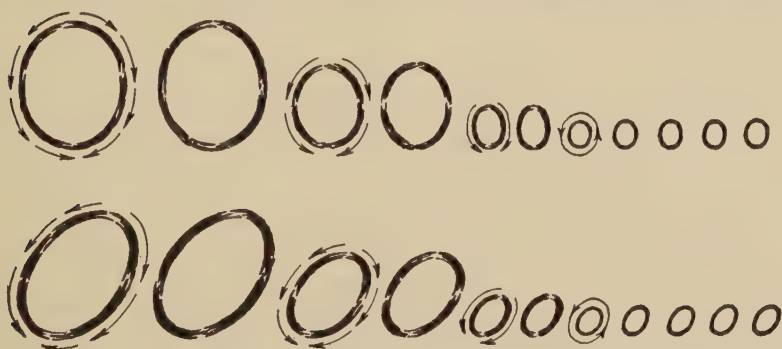


FIG. 6. Method of developing standard oval.

to combine them in forming such letters as *b, d, p, n, r, u*, etc. The secret of success lies chiefly in remembering that the stem becomes one side of the parallelogram shown in Fig. 5, and that, in making the stem tangent to the oval, it will be found in practice that they must coincide with each other for some distance, as shown in Fig. 7.

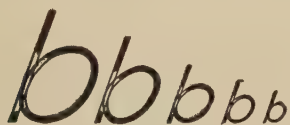


FIG. 7. Combined stem and oval.



FIG. 8. Incorrect ovals "Pumpkin seed."

The oval should not be allowed, on this account, to degenerate into the form shown in Fig. 8, called the "pumpkin seed" letter, a form which is used by many engineers because of its easy construction, and in which the juncture of stem and oval is hardly more than a point. Another common inexcusable distortion of the oval in many of the small letters is shown in Fig. 9, where only a part of the oval is used, either alone or in combination with the stems. The

corners indicated on the upper right segment of the oval rapidly become very sharp and detract materially from the beauty of the alphabet.

A second element of success consists in making the stem and oval of the same weight, both when combined and when made separately. It should be observed in Fig. 7 that the weight of stroke varies directly with the size of letter, the larger letters having a width of stroke equal to about one-sixth the height, while the smaller letters are correspondingly decreased to the limit of the pen being used.

A third element entering into the successful construction of the alphabet, perhaps to a greater degree than either of the other two enumerated, is that of the width of each letter. Even a cursory

f h n m p r

FIG. 9. Incorrect ovals sharp corners.

examination of the alphabet is sufficient to impress upon the eye the necessity of varying the width of different letters to accommodate their shape to each other. In short, each letter must be propor-

tioned upon some general principle or rule, often called the "rule of stability," which will take care of these differences due to shape and make proper allowance for balance in each letter.

Rule of Stability. — An examination of such capital letters as *A, F, J, K, P, T,* and *V* discloses at once the fact that, on account of their unsymmetrical form, some contraction should be made in the width of each to prevent them from appearing either top-heavy or bottom-heavy, as the case may be. Likewise, the mass form of *M* and *W* requires that they be made wider than the normal letter. Again, it is a well-known fact that a horizontal line drawn through the middle of an upright rectangle appears to be below the center of the rectangle, or, in other words, the top area appears greater than the bottom area. This optical illusion has an effect on such letters as *A, B, E, F, H, K, P, R, S,* and *X*.

The rule of stability takes all these factors into account by requiring that the irregular white surfaces enclosed by black lines appear to be balanced in each letter. The small tops of the letters *B* and *S* and the numerals *2, 3,* and *8*; the high position of the bar in *H*, as well as the high crossing of the two strokes in *X*; the low position of the bar in *A*; and many other variations should be noted in this connection, as they result from a direct application of the rule of stability. Figure 10 shows the approximate relation which

the widths of the various capital letters bear to each other, and the values should be committed to memory. The numbers given are to be thought of in terms of the height of the letter, which is divided into six equal parts irrespective of the size of the letter. The

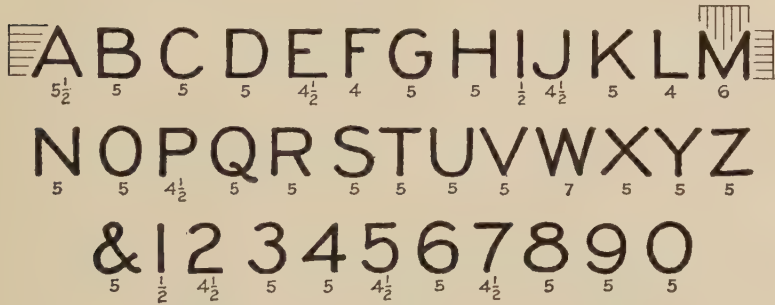


Fig. 10. Approximate widths of standard letters.

small letters are more uniform in shape, and little can be done in the way of varying their width to improve their appearance.

SLOPE. — What has been said thus far applies equally well to slant or vertical letters, as indicated in Figs. 4 to 9, inclusive. As

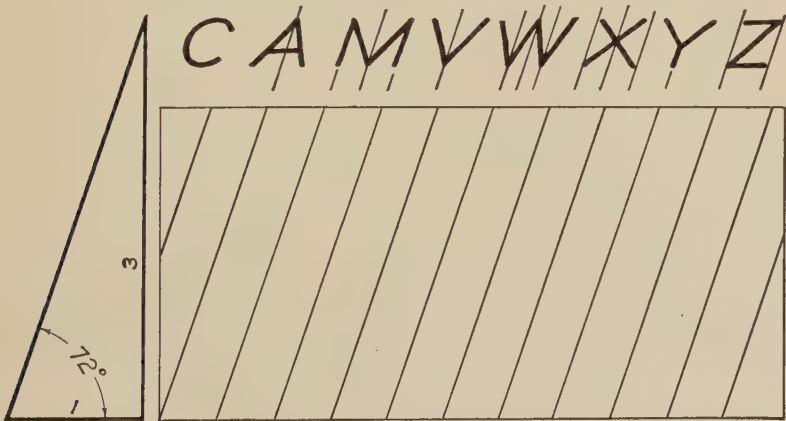


Fig. 11. Lettering slope guide.

has been stated in a previous paragraph, the standard slope of letters should be 72 degrees. This slope may be obtained approximately by laying off a one-to-three triangle, as shown in Fig. 11. All stems, as well as the sides of the parallelogram enclosing the

ovals, should be made parallel to the hypotenuse of the triangle. It will be noted that the major axis of the ellipse in slant lettering is nearly 45 degrees to the horizontal, and that the points of tangency occur at the midpoints of the parallelogram, as shown in Fig. 5. It should be further noted that the *median line* of the letters A, V, X, and Y is parallel to the standard slope.

A good practice for the beginner to follow is to lay off, on a stiff piece of paper, a Slope Guide similar to the one shown in Fig. 11, which can be placed just below the line on which the lettering is being done and thus aid the eye and hand in acquiring the proper slope.

GUIDE LINES. — In doing lettering on drawings or in compact composition, it is found impossible to maintain perfect alignment

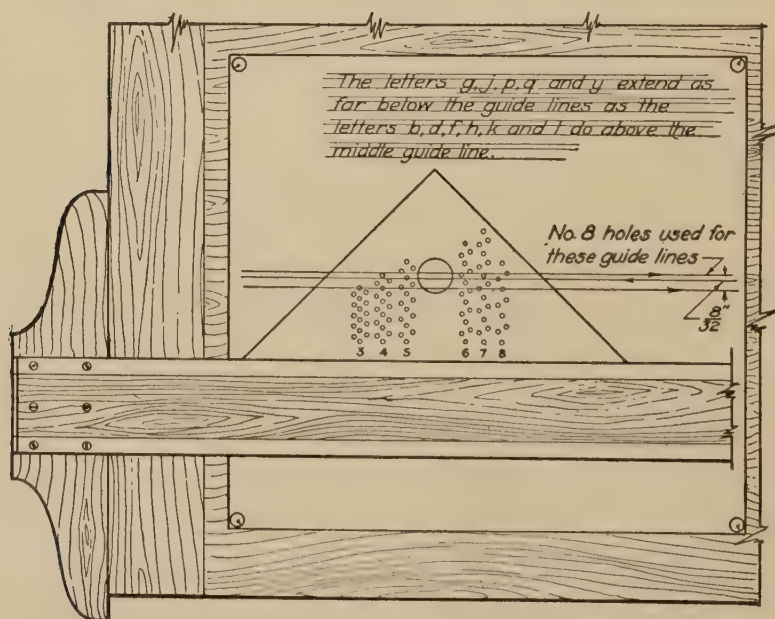


FIG. 12. Lettering triangle to rule guide lines.

and correct height of letters without the use of mechanical aids called Guide Lines. These consist of three parallel, light pencil lines ruled with T-square or triangle on the space to be occupied by the lettering. The distance between the two outside lines is made equal to the chosen height of letter. The third line is ruled above the bottom or base line a distance equal to two-thirds the height of the letter.

For ordinary work, letters three-sixteenths or one-eighth inch in height are employed, the latter being the more generally used. Both these heights, as well as many others, may be obtained on the Braddock and other lettering triangles and their use saves much valuable time. Figure 12 indicates the method of ruling guide lines with such triangles. Attention is called to the Arabic numbers printed at the bottom of each column of drilled holes in the triangle. They express, in thirty-seconds of an inch, the vertical distance between the lower and upper holes in a set of three. Thus, if one wishes to have the upper and lower guide lines five thirty-seconds of an inch apart, he should use the column marked with the numeral five. It is also important to know that each set of three holes in a column is so spaced, in reference to its neighbors in the column, that the proper distances between lines of words is assured if one rules in several guide lines at one setting of the T-square.

The triangle should be moved back and forth on the T-square edge, with the pencil point inserted in adjacent holes as the ruling progresses down the page. After considerable skill in lettering has been acquired, either the upper or middle guide line may be omitted, but in no case should one attempt to do any work with only a single guide line.

Position of Letters on Guide Lines. — All capitals and the stems of the small letters *b*, *d*, *f*, *h*, *k*, and *l* have their tops and bottoms resting on the two outer guide lines. The short stems and ovals in the small letters fall between the two lower guide lines. It will be found that the letters *c*, *e*, and *o*, on account of their shape, appear lower than other letters of their height; hence, when used adjacent to such letters in a word, these three ovals should be carried slightly above the second guide line.

In the case of letters *g*, *j*, *p*, *q*, and *y*, the bottom part of the stroke is carried below the lower guide line a distance equal to one-third the height of the letters, or, in other words, as far as the upper guide line is above the second. This is always done by eye and not with the aid of a fourth guide line.

The dots over the small *i* and *j* are placed midway between the second and third guide lines. The short cross lines on the letters *f* and *t* are sometimes raised slightly above the second guide line in lettering compact composition, but theoretically they should be put on the guide line.

DIRECTION OF STROKE. — In making the several letters of the alphabet, two general principles should be followed as regards direc-

tion of stroke, viz., all stroke motions should be from the top of the sheet towards the bottom and from left to right. Adherence to these principles will be sufficient guidance in making any letter, although some variations from them prove advantageous, especially in the case of very small letters where a single stroke may be sub-

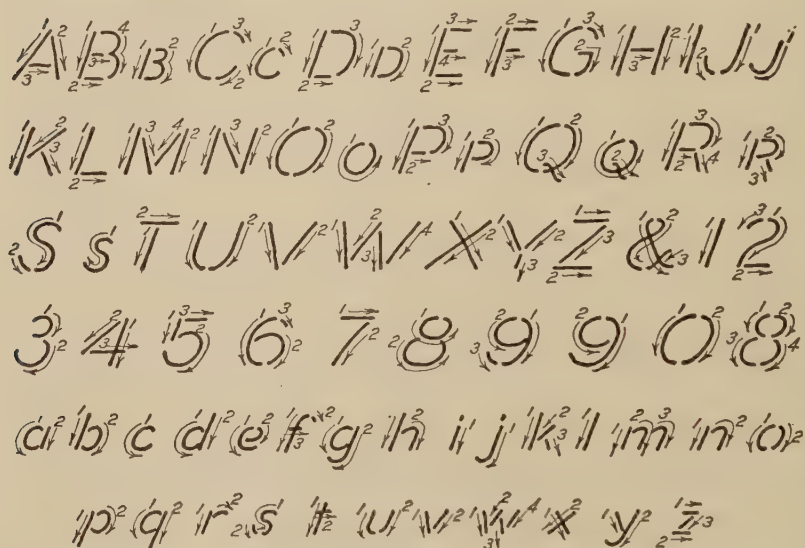


FIG. 13. Direction of pen strokes.

stituted for two required by rule. The direction of strokes for each letter in the alphabet is given in Fig. 13. Suggested variations, due to size of letter and other reasons, are shown. It must not be assumed that the pen is taken from the paper at the end of each stroke to begin the succeeding stroke; the arrows indicate the order and direction of strokes only. One's judgment is sufficient guide in determining when it is best to combine any two strokes.

NUMERALS. — Very great care is necessary, in preparing drawings and estimates, to see that no ambiguity arises, especially in regard to actual sizes of parts, amounts required, and cost of same. For this reason the engineer sticks closely to the use of numerals approved by his profession. Commercial styles should never be tolerated, and attempts to "individualize" the numerals on strictly engineering drawings should be condemned altogether. A close inspection of Fig. 14 reveals the fact that the numerals are in large part built up from the two elements used in forming the alphabet,

The height of the numerals is the same as that of the capital letters with which they are used. Care should be taken to have the ovals open and full, as serious errors may otherwise occur, owing to the likeness between 3 and 5 and between 3 and 8, for instance. Note the reversibility of the 6 and 9; the small tops of the 2, 3, and 8; the closed-topped 4; and the alternative forms for 3 and 7. In the case of the 3 and 7, it is recommended that the form printed first in the figure be used on all engineering drawings.

In fractions, the height of the numerals in numerator and denominator should be two-thirds the height of the integer, i.e., equal to

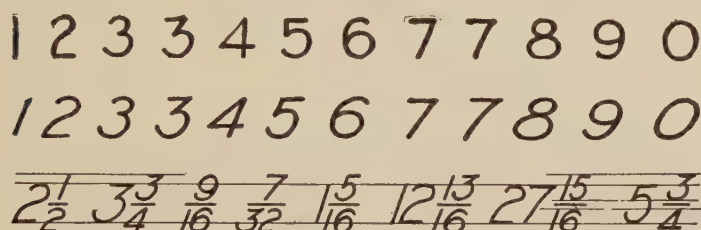


FIG. 14. Engineer's vertical and slant numerals.

the body of the small letters. A horizontal bar should separate the numerals, and a clear space should be left between it and each number.

COMPOSITION. — The chief reason why so much poor lettering is turned out is that many draftsmen fail to acquire the knack of good composition. By good composition is meant that careful spacing of letters in words, and words in sentences, which compels the instant approval of the observer because of the ease with which it is read, the life and snap it possesses, and the pleasing effect it has upon the eye of the reader. These three most desirable qualities cannot be secured with scale and dividers or by any "rule of thumb." One underlying principle, called the Principle of Balance, must be relied upon, since no Table of Spacing, however complete, could cover the multiple combinations of letters and words which may occur. Effect is given to this principle through the trained perception of the letterer alone; and no mechanical devices, however efficient and elaborate, will take the place of the critical and artistic demands of the human eye.

Principle of Balance. — Concisely stated, the Principle of Balance simply requires that the area of the white spaces between ad-

jacent letters shall be approximately equal to each other and that the white areas between successive words shall appear the same. Further, in order to make the text matter readable with ease and rapidity, these areas between letters in words should be as small as practicable with a corresponding fullness in the letters themselves. The chief offense against good lettering committed by beginners is the universal tendency to separate the letters by excessively large spaces. Beauty of style is obtained more through compact and uniform composition than through excellence in fashioning the letters themselves.

In spacing words in a sentence, a good rule to follow is to make the distance between adjacent words equal to the height of the let-

*Open spacing, although uniform,
makes the composition difficult
to read.*

*Uneven spacing is repulsive to the eye,
and in many instances is unreadable.*

*Lack of uniformity in slope of stroke
gives to the composition a very bad
appearance.*

*Compact and uniform lettering is not only
easily read, but is beautiful as well.*

FIG. 15. Examples of good and bad composition.

ters. Taste will dictate minor variations from the rule cited, but excellent results will follow from its general application.

Figure 15 illustrates the points just emphasized. A close inspection of the faults graphically portrayed will serve to prevent much loss of time and also aid in perfecting the student's own composition.

Refinements in Composition. — In order to secure perfect balance in composition, it has been found necessary to modify certain letters in the alphabet when followed by certain other letters. For instance, in Fig. 16 the word LATTICE has been materially improved by narrowing both *L* and *T*, thereby reducing the large amount of white space between them and the adjacent letters. The

word WAVERLY has also been improved by overlapping the letters *W*, *A*, and *V*, as well as *L* and *Y*. Similar improvements can be effected with the small letters. Thus, for instance, in combining the oval with the stems of such letters as *b*, *d*, and *p*, it will be

Failure was caused by insufficient
LATTICE BARS.

The bridge is located at
WAVERLY, MASS.

FIG. 16. Correct composition of difficult combinations.

found that a slightly less inclination of the axis of the oval to the horizontal than that used in the ovals *c*, *e*, and *o* when uncombined with stems, improves the composition appreciably. A somewhat

ABCDEFGHIJKLMNOPQRSTUVWXYZ&

abcdefghijklmnopqrstuvwxyz

A B C D E F G H I J

K L M N O P Q R S

T U V W X Y Z &

a b c d e f g h i j k l m

n o p q r s t u v w x y z

FIG. 17. Compressed and expanded alphabets.

similar improvement can be effected in *h*, *n*, and *m* by turning the hook more sharply than would be the case were the full oval used. The student should study his composition carefully with the thought of improving it by the means described.

COMPRESSED AND EXPANDED LETTERS. — Very often the space available for a certain number of words is so small that the normal letters cannot be used, e.g., in a title or legend. To overcome this difficulty, each letter is made narrower than the normal width by compressing the ovals. This type of alphabet is known as the Compressed Alphabet. For diametrically opposite reasons, the letters may be widened, and the resultant alphabet is known as the Expanded Alphabet. Both alphabets are shown in Fig. 17.

Such distorted letters serve a very useful purpose in emphasizing material by making it contrast with other material of its kind. The compressed or expanded letters are made as readily as are the normal sizes, and the difficulties of composition are on the whole lessened; but the effect on the eye is not as pleasing, and the text is not as easily read.

SMALL CAPITALS. — In many drafting rooms it is the practice to use capital letters almost exclusively on the drawings turned out. In other places it is customary to use the capitals for legends, names of parts, or in the bill of materials. This practice has given rise to the use of a sub-capital letter called the Small Capital. The height of the small capitals is two-thirds the height of the larger ones being used with them, with a corresponding reduction in width. In every other way the two are alike. The custom of combining the two sizes, however, has little to recommend it, except the element of individuality and the similarity of each draftsman's work; the letters are made less rapidly and are more difficult to read than the lower case letters which resemble the type to which the eye is accustomed in everyday reading.

SUMMARY OF PRINCIPLES. — From the foregoing discussions there is derived the fact that good lettering depends upon a certain uniformity of execution in five distinct ways, namely, uniformity of style, weight, slope, size, and spacing. These five items are easily kept in mind. They enable the student to concentrate his attention upon those points where trouble arises, and permit him to judge his own work accurately when it is finished.

Uniformity of style prevents the indiscriminate mixing of Gothic and Roman letters, and of upper and lower case letters, except for the legitimate purpose of capitalization.

Uniformity of weight is attained by careful attention to the filling of the pen which should never be overfilled nor allowed to run dry. A steady, uniform and light pressure should be maintained at all times. Certain special lettering pens are a great aid in attaining this objective.

Uniformity of slope is attained only through careful practice, but it may be more easily acquired through the use of slope guide lines.

Uniformity of size and spacing are again matters of patient practice. The former is secured by means of ruled guide lines. The latter is secured by applying the rule of balance which requires that the black and white areas in words shall be equal.

DRAWING PENCILS. — For ruling guide lines and layout work pencils as hard as 5H or 6H should be used. For actual lettering work, 2H and 3H pencils are best. Reference to pencils is made by giving the degree of hardness of the lead. This hardness is expressed in terms of the letters B, F, and H, the softer pencils being graded in varying degrees of B and F, while the engineer's pencils are graded in terms of the letter H, as follows: — soft 2H and 3H, medium 4H and 5H, hard 6H and 7H. The *number* on certain pencils should not be confused with these degrees of hardness, as many companies do not indicate this quality of the lead in terms of the standard letters.

LETTERING PENS. — In the preceding paragraphs on Composition of Stem and Oval, and in the illustrations in Fig. 7, it has been shown that the width of the pen stroke should be proportional to the height of the letters. It is necessary, therefore, to provide one's self with several types of pens in order to allow latitude in the choice of sizes of lettering to be used.

For the ordinary height of lettering used in dimensioning drawings, a light ball-point pen is very successful. For larger work, either No. 510E.F. or 516E.F. ball-points, made by P. Leonardt and Company, England, are desirable. Gillott's No's. 404 and 303 are well suited for finer work. The E. G. Henry Tank Pens are very satisfactory pens since they may be obtained with the straight or ball-points and are equipped with ink wells. See Fig. 19. For large letters the Payzant pen will be found useful. Figure 18 shows some special lettering pens suited to special needs.

Pens should be "broken in" by preliminary use before being considered fit for work on valuable drawings. They generally come to the draftsman smooth and slippery on account of a thin coat of oil on the surface, which prevents the ink from clinging to them in an even coating. This may be overcome by dipping in alcohol or burning with a lighted match. The pen holder should be provided with a rubber grip of a size suited to the hand of the letterer. Ink should not be allowed to dry hard on the pen, pains being taken to wipe the nibs dry and clean after each few minutes

of use. The pen should be inked on the inside only, by means of the quill in the stopper of the ink bottle instead of by dipping it in the bottle itself.

One of the chief difficulties encountered in lettering is that of keeping the weights of letters the same throughout the whole com-

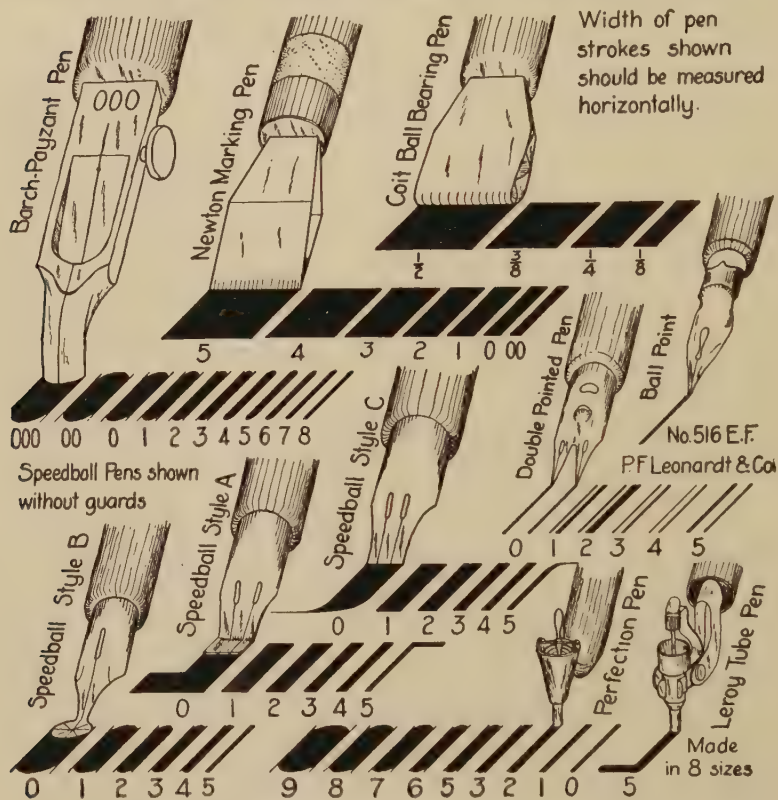


FIG. 18. Weight of lines with special pens.

position. Especially is this true between the last letters made when the pen is running dry of ink and the letters made just after the pen has been inked. This trouble can be overcome to a large extent by improvising a simple guard for the pen point, which will serve to carry more ink at each filling and to distribute the flow more evenly over the entire period of use. A simple and effective device is that of bending a small piece of brass or steel into the shape shown in Fig. 19 and inserting it in the under side of the pen-holder grip in the manner shown in the figure. A leg of the well-

known brass binding staple will do for this purpose. Commercial guards may be purchased, or somewhat the same result may be attained by simply wrapping the pen point with a small rubber band. Several lines may be printed without re-inking the pen, if these or similar devices are used. In every way the draftsman

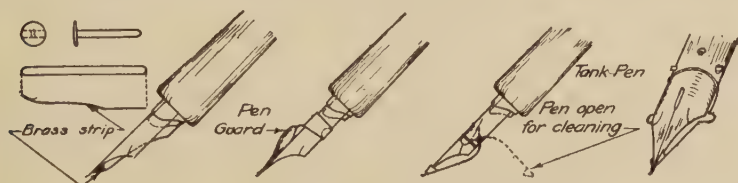


FIG. 19. Pen guards.

should treat his lettering pen as one of his most useful tools and care for it accordingly.

MECHANICAL LETTERS. — By Mechanical Letters is meant an alphabet *constructed with the aid of instruments*, in contradistinction to those *done freehand*. Although for ordinary use such letters are to be condemned completely, many instances arise where a mechanically constructed letter may be justified. In the case of very large letters for inscriptions or panel work, it might be found advantageous to lay out the lines with the aid of T-square, triangle, and compass. In constructing a large title with the Roman alphabet, excellent results can often be obtained with mechanical aids, and their use is recommended. The engineer's scale proves of little help in this connection, since the units of measure to be used cannot be obtained from it directly. A new scale has to be devised for each size of letter, since the **unit** varies directly with the height of the letter.

Unit of Measure in Lettering. — The unit of measure to be used in the construction of mechanical letters is either one-sixth or one-seventh the height of the capital letter chosen for the particular piece of work at hand. The widths of letters, distances between letters, widths of stems and ovals, and the location of centers for serifs and ovals are then expressed in terms of this standard unit. Reference to Section 2 of this chapter will make clear the method of constructing a mechanical alphabet. A study of the figure there shown will serve to fix in mind the proper ratio of the width of each letter to its height when freehand lettering is being done, since the values shown are approximately those to be used in freehand work.

CHAPTER II

LETTERING

SECTION 2

The five following alphabets have already been alluded to in Section 1 of this chapter. They are included in this work both on account of their historical interest and their general utilitarian aspects.

Figure 1 is believed to be a faithful representation of the Old Roman alphabet as it was developed in the first and second centuries A.D. The root forms are taken from the inscription on the base of the Trajan column at Rome, which is said to have been cut in 114 A.D. The authors are indebted to Mr. Frederick Goudy's excellent work, *The Alphabet*,¹ for the reconstruction of the letters, the outlines of which they have carefully copied.

Figure 2 represents the first Roman type of distinction to be used in England. It is said to have been cut by the printer, Caslon, in 1724. This alphabet also has been faithfully copied from its reconstruction by Mr. Goudy.

Figure 3 is representative of the several modified forms of the Old English alphabet now in existence. It combines simplicity of design with a dignity of character sufficient to make it acceptable for most ornate work.

Figure 4 contains typical alphabets found on architectural plans and drawings. Although composed of simple characters which are easily mastered, they possess enough of the beautiful and distinctive qualities of more ornate forms to make them compatible with the character of the drawings upon which they are used.

Figure 5 shows the Modern Roman alphabet as it is used today on maps and inscriptions. Its stately beauty can hardly be denied. It is recommended that, when used in the larger sizes, the outlines of the letters be constructed mechanically, as suggested in the figure.

¹ *The Alphabet*, by Frederick Goudy.

Figure 6 suggests what may be done, with speed and ease, when conditions demand large uniform titles, in the way of mechanically constructed alphabets. The severe Gothic alphabet there shown is typical of what may be done in other alphabets by proper adaptation. Mechanically made alphabets are, of course, to be shunned except in limited fields, as previously explained.

BIBLIOGRAPHY

- LETTERING FOR DRAFTSMEN, by C. W. Reinhardt. D. Van Nostrand, New York, 1919.
- PLAIN LETTERING, by H. S. Jacoby. Engineering News Publishing Company, New York, 1911.
- TREATISE ON HAND LETTERING, by W. J. Lineham. E. P. Dutton, New York, 1915.
- FREEHAND LETTERING, by F. T. Daniels. D. C. Heath and Company, Boston, 1907.
- ALPHABETS AND OTHER MATERIAL USEFUL TO LETTERERS, by Charles Rollinson. D. Van Nostrand, New York, 1912.
- THE ART OF LETTERING, by C. L. Svensen. D. Van Nostrand, New York, 1924.
- LETTERS AND LETTERING, by Frank Chouteau Brown. Bates and Guild Company, Boston, 1921.

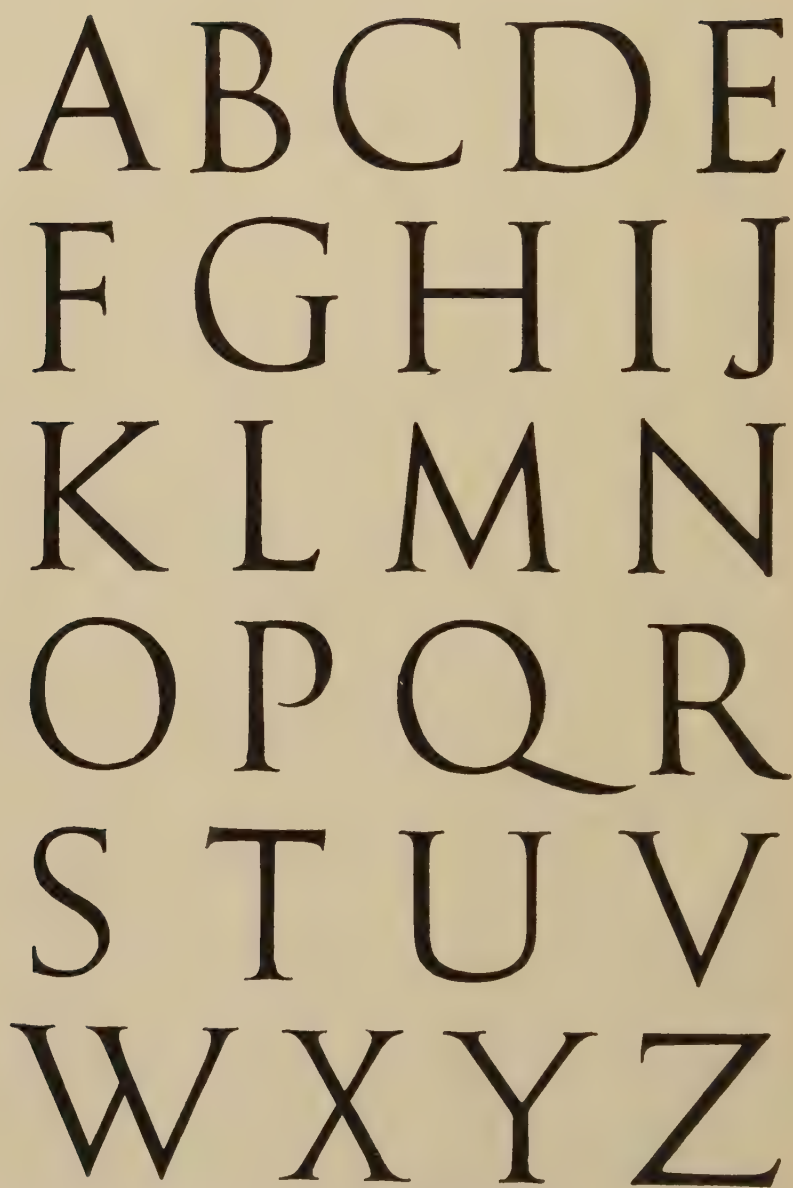


FIG. 1. Old Roman alphabet.

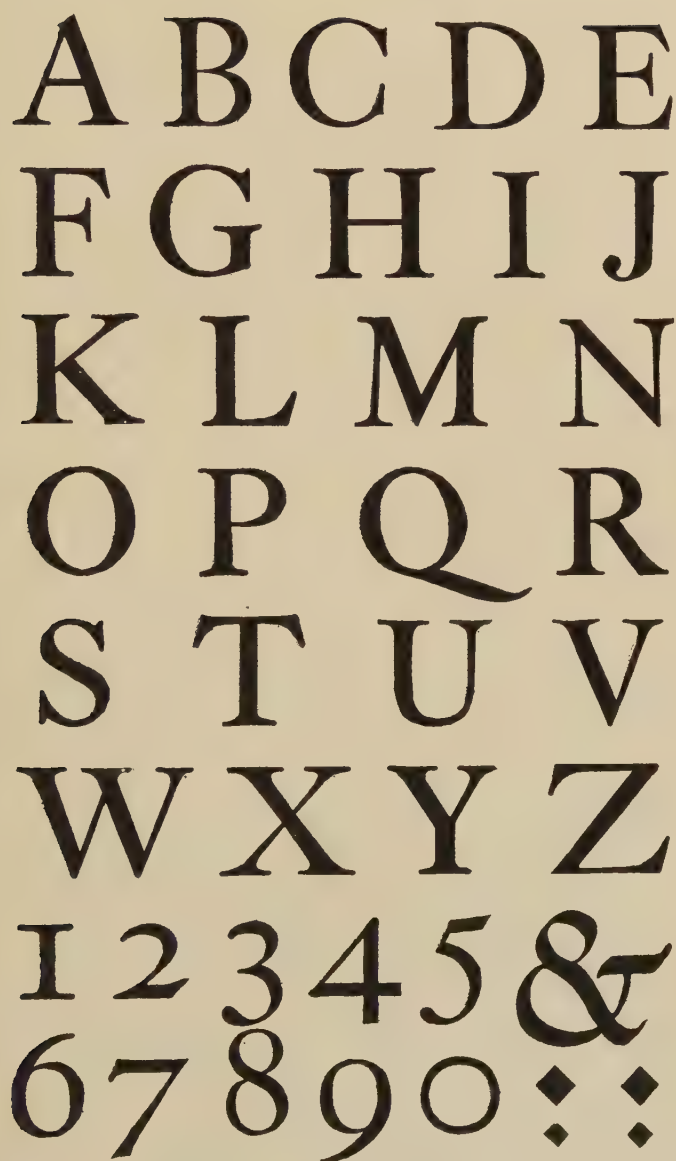


FIG. 2. Early Roman type.

~ Old English ~

A B C D E F G H I
 J K L M N O P Q R
 S T U V W X Y Z &
 a b c d e f g h i j k l m
 n o p q r s t u v w x y z
 1 2 3 4 5 6 7 8 9 0

~~~~~

Several modified styles of Old English are in common use. The above alphabet can be easily and quickly executed.

~~~~~

The artistic and stately appearance of the Old English Alphabet makes it peculiarly adapted for use on charters, certificates and diplomas.

~~~~~

John Edward Browning,  
 Bachelor of Science.

FIG. 3. Old English.

## CHAPTER III

### TITLES

A drawing, like a piece of literature, must have a title. This title serves as a means of identification while the drawing is in use, and as a means of reference for correspondence, indexing and filing. It may serve to convey certain specific information, such as the name of the draftsman, the scale and date of the drawing, or perhaps a statement of the purpose for which the drawing was made.

The importance of a proper title cannot be overestimated. While a draftsman *may* be able to recognize his drawing and tell all about it six months or a year after he has made it, the *probability* is that he will *not* be able to do so, and it is certain that another man would have considerable difficulty in identifying the drawing and making any use of it. For this reason, every drawing, even though it be only a rough preliminary pencil sketch, should have some title.

In order that a title may serve as a means of identification, it must tell briefly what the drawing is. Hence, the name of the object drawn should always appear, and sometimes a statement of the kind of drawing, as for example, Detail of Crankshaft, Gas Engine "E," or Assembly of Turret Lathe No. 3074. The words Detail and Assembly specify the kind of drawing, while the other words name the object. Where the object shown on the drawing is not stock work, the title should also give the name and location of the person for whom it is to be made. This is essential, as it serves to identify two pieces which may be quite similar but which are to be made for two different persons and must be shipped to different points.

The title should also contain the name and location of the manufacturer when he makes both the drawings and the machine or structure; otherwise it should contain the name of the architect or engineer who designed the machine or structure. The scale of the drawing is also essential, and the date is always of sufficient importance to be included. An index or filing number must also be provided for. If the sheet is one of a large number which belong to the same project, it must be given a sheet number.

An examination of drawing titles will show that the foregoing items are included in almost every one. See Fig. 1. Practice varies somewhat in regard to making the draftsman's name a part of the title. In many titles a place is provided for the initials of the draftsman, tracer, and checker, and also for the signature of the engineer in charge when he has approved the drawing. This is a

| REVISION |               |    |      | SANDBLAST EQUIPMENT |                 | BROOKER & WAVERLY       |       |
|----------|---------------|----|------|---------------------|-----------------|-------------------------|-------|
| No.      | CONSISTING OF | BY | DATE | STROM FISHER & CO   |                 | ENGINEERS & CONTRACTORS |       |
|          |               |    |      | CHAMPAIGN, ILL.     |                 | CHICAGO, U.S.A.         |       |
|          |               |    |      | DRWG No.            | Req. No.        | WAREHOUSE               |       |
|          |               |    |      | Description         |                 | For                     |       |
|          |               |    |      |                     |                 | UNION TOBACCO COMPANY   |       |
|          |               |    |      |                     |                 | At                      |       |
|          |               |    |      |                     |                 | MEMPHIS, TENN.          |       |
|          |               |    |      | DRAWN               | TRACED          | DATE                    | SCALE |
|          |               |    |      | SCALE               | DATE            | REVIS                   | REVIS |
|          |               |    |      | APPROVED            | CHIEF ENGINEER  | 1642 12                 |       |
|          |               |    |      |                     | GENERAL MANAGER |                         |       |

| 2 | 1 | REVISION No. | APPROVED | CHIEF DRAFTSMAN | JONES & COMPANY              | MICHIGAN COKE Co        | SCALE |
|---|---|--------------|----------|-----------------|------------------------------|-------------------------|-------|
|   |   | NAME BY      |          | ASST. " " "     | CONSTRUCTORS OF REGENERATIVE | REVERSING MECHANISM &   | 13421 |
|   |   | DATE         |          | SUPERINTENDENT  | BY PRODUCT COKE & GAS OVENS  | DECARBONIZING APPARATUS |       |
|   |   | CHECKED BY   |          | CHIEF ENGINEER  | CLEVELAND, OHIO.             | ELEVATIONS BATTERIES    |       |
|   |   | DATE         |          |                 |                              |                         |       |

FIG. 1. Examples of commercial titles.

practice to be recommended, as it places responsibility quite definitely and a realization of this responsibility in the drafting room makes for better work.

Having clearly in mind the purpose which the title is to serve, and having determined the matter which is to be put into it, the question of the best design of the title must be considered.

**DESIGN OF TITLE.** — The problem of designing a title involves six factors affecting its appearance and usefulness, namely, location on the drawing sheet, size, shape, style of letters, order of prominence, and balance or symmetry.

**Location of Title.** — The position of a title on the drawing sheet is largely determined by the ease with which it may be examined when the drawing is filed in cases and racks. Almost invariably the title will be placed in the lower right-hand corner of the sheet, or on the middle right side; it is sometimes found at the right top of the sheet. For machine drawings the first-named position is preferable and is almost always used by manufacturing concerns. For drawings which are to be reduced photographically and used in bulletins and books, the title is not lettered in on the drawing proper, but is set in type and placed in the center at the top or bottom of the sheet. The content of such a title is usually limited to a brief phrase or sentence stating what the drawing is.



**Size of Title.** — The first question which confronts the draftsman is, "How large shall the title be?" Obviously, it should be large enough to be readily seen and read, while at the same time it must not be so large as to be obtrusive and detract from the drawing itself. A very large drawing must have a title of considerable size to give it the proper dignity and satisfactory appearance, but a large title on a small sheet would clearly be inappropriate. Consequently, the size of the drawing sheet and the contents of the title will be the governing factors in deciding what space to allow for the title itself.

When the matter to be put in the title is of a somewhat standard character in form and quantity, it is customary to make the length and width of the title space correspond to the length and width of the sheet, although some excellent titles which do not follow this practice may be found. An examination of titles will show that on the standard drawing sheets, e.g.,  $12'' \times 18''$ ,  $18'' \times 24''$ , etc., a pleasing size for the title space can be obtained by making the width and length, respectively, somewhat less than 15 per cent and 25 per cent of the short dimension of the sheet. On the other hand, if the contents of the title should be the determining factor, it will be a good rule to make the height of the largest letters not over 2 per cent of the short dimension of the sheet. In some cases, however, the size of the title space will be limited because of the drawing; hence it should be remembered that no hard and fast rules can be laid down, but that in each case the sense of proportion and good judgment must prevail.

In some drafting offices, the title is put on in the form of a narrow strip across the bottom of the sheet and is called a Record Strip. It is usually divided into small compartments, each of which contains a certain part of the title. An example, greatly reduced, is shown in Fig. 1. For some purposes this form of title is quite desirable, since additions can be made to it without difficulty. In case this kind of title is used, each subdivision should be treated as a title by itself insofar as the arrangement of the matter to be put into it is concerned.

**Style of Letters in Title.** — After the title space has been determined, the next thing in order is to choose a *style* of letter suitable to the character of the drawing.

For engineering drawings the choice of styles is limited to simple variations of the two major alphabets, i.e., Gothic and Roman. The day of fancy letters has passed, and the only variations which

good usage now permits are a change in the height, width, weight, or slope of the letters. The title must be neat and business-like and not a time-consumer in its construction. Hence the usual practice today is to make machine drawing titles in vertical or slant Gothic. As a rule, the most prominent parts of the title are lettered entirely in capitals. Since the Gothic can be made quite rapidly with single strokes, this type is to be preferred for shop

|                                                    |                                                                     |
|----------------------------------------------------|---------------------------------------------------------------------|
|                                                    |                                                                     |
| Drawn by, RPH<br>Checked by, FMP<br>Traced by, RPH | Scale, $\frac{1}{2}'' = 1''$<br>Date, Feb 2, 1923<br>Appr by H.H.J. |
| Drawn by RPH<br>Checked by H.H.H<br>Traced by RPH  | Scale $\frac{1}{2}'' = 1''$<br>Date, Feb 2, 1922<br>Appr by H.H.J.  |

FIG. 2. Shop drawing titles.

drawings. See Fig. 2. For drawings requiring a little higher finish, the heavy or bold-face Gothic is quite appropriate, see Fig. 3, while the Roman, which requires the most time and skill to execute well, is generally reserved for drawings of a highly finished

|                                                                                                                                                                           |                                    |                                                           |                          |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|-----------------------------------------------------------|--------------------------|
| DETAIL OF<br><b>CONNECTING ROD</b><br><b>PUMPING ENGINE NO. 1327</b><br>FOR THE<br><b>PUBLIC UTILITIES CO. SPRINGFIELD, ILL.</b><br><b>BROWN ENGINE CO. CHICAGO, ILL.</b> |                                    |                                                           |                          |
| SHEET No.<br><b>2</b>                                                                                                                                                     | Drawn by<br>Checked by<br>Appr. by | Traced by<br>Scale $\frac{1}{4}'' = 1''$<br>April 21 1922 | Order No.<br><b>1426</b> |

FIG. 3. - Heavy face Gothic title.

character, such as display drawings, Government maps, etc. The size of title space and style of letters may be chosen without special reference to the actual wording of the title.

The style of lettering is usually fixed in a commercial drafting

room to give uniformity to all the work turned out, so that the draftsman's first task is to arrange his title matter into lines and to space and group these lines so as to secure the best effect in the chosen title area. In doing this the draftsman must consider several things at the same time, such as the prominence to be given certain words, the contour of the title as a whole, and the balance, or symmetry, of the title when finished. As a preliminary step it is best to write out the title in long hand, arranging the lines with a view to obtaining a pleasing appearance and giving proper weight or prominence to important parts.

**Prominence of Parts of Title.** — The principle upon which the order of prominence is based, is simply to make most emphatic the item which best describes the drawing for identification purposes. Other items then follow in the order of their importance. Obviously, the name of the object drawn is of primary importance, while the name of the party for whom it is to be made stands a very close second. The manufacturer's name should have about third rank, but as a matter of advertising it is usually made most prominent. One would not care for the scale, date, or draftsman's name unless he were making a careful examination of the drawing; hence these items are of minor importance, although absolutely necessary. On ordinary titles such as those shown in this chapter, there may be four or five degrees of prominence, with a commensurate number where the matter to be included covers a wider range.

Prominence may be secured in several ways, for example, by increasing the height or width of letters, by changing the slope, or by making any other noticeable alteration in the style or shape of the letters. See Fig. 2. A line may also be made to stand out by extending it in each direction some distance beyond other lines.

**Contour of Titles.** — By this term we mean the outline shape of the title itself or, better still, the shape of the figure enclosed by drawing lines tangent to the ends of the consecutive lines of the title. See Fig. 2. The contour should enclose a regular symmetrical figure, the simpler forms being the more desirable.

**Balancing Titles.** — By the term *balance* we mean the symmetrical distribution of the lines around a vertical center line and the equal or uniform arrangement of black and white spaces. In other words, the margin at the left of the title should be equal to that on the right, likewise the spaces at the top and bottom should be very nearly equal. In order to balance black and white spaces, the

most important lines should not be at the very top, but rather as near the center as conditions will permit. One or two comparatively heavy lines above the most prominent line will, of course, balance a greater number of lighter ones below it. A title can be balanced in other ways than the one indicated, but this is the customary drafting room scheme.

It is possible, of course, to balance a title by a cut-and-try process, first lettering lightly in pencil the outlines of the letters and then erasing and relettering where the first trial was unsatisfactory. For small titles of few words this scheme is sufficiently rapid and accurate, since with a little practice one soon learns to estimate the proper amount of space to allow for various words and phrases. With large titles, however, such as title sheets for sets of drawings, it will save time to adopt the scratch paper scheme suggested below.

Assuming that the size of the letters for each line has already been determined on the basis of the prominence desired, guide lines for each line in the title are ruled on separate strips of paper a little wider than the height of letters. A length is marked on the scratch paper strip approximately equal to the length which it is desired the line shall occupy and the words are then put in with single-stroke Gothic letters.

After each line of the title has been made on a strip of paper, all of the strips may be assembled in the title space at once, and shifted around until a satisfactory balance is obtained. Then both the guide lines and location of letters may be readily transferred to the drawing paper and the work completed.

**FINISH OF TITLE.** — The term “finish,” as applied to a title, has much the same meaning that it has when applied to machine parts. Machine parts may be finished to a hundredth of an inch or to one ten-thousandth of an inch, depending upon their use. In much the same way, the use of the drawing upon which the title is placed determines the degree of finish it is justifiable to impart to the title. For working drawings to be used only in the shop, the single stroke or bold-faced Gothic is sufficient. For display drawings the modern or old Roman is more appropriate and may be done freehand or with instruments, depending upon the size of the letters and the skill of the draftsman. Greater care must be exercised in the construction of such titles, and the same finish should be given to all parts. Titles on drawings intended for photographic reproduction should be carefully finished off, as defects are not eliminated by reduction.



**EMBELLISHMENTS.** — Occasionally, in order to balance a title or to break up large white areas, embellishments in the form of little scrolls or geometric figures are added. If properly executed and used sparingly, these add considerably to the appearance of an open title.

**SUB-TITLES.** — It frequently happens that a drawing sheet will contain several details. It is then necessary to distinguish each part by a sub-title of some kind. Ordinarily this consists simply of the name of the piece, but sometimes other words of explanation are needed. Such titles on machine drawings should be made in small, single-stroke Gothic letters. If possible, the center of the line should come under the center of the detail to which it belongs.

**MODERN TITLE-MAKING METHODS.** — In a complete set of drawings, it is desirable that all of the lettering, and particularly the titles, have the same characteristics. This may be accomplished by having one man do all of the lettering in ink, but this plan cannot always be followed. Moreover, title making at best is a slow process whether one man or several do it. Therefore, to speed up the work and at the same time to provide greater uniformity, several labor-saving methods have been worked out. One of these is to have the border line and title printed on standard size sheets. Such parts of the title as the company's name and location, the words Drawn by . . . . ., Checked by . . . . ., Scale, File No., etc., are printed. The other words, of course, must be lettered in. One difficulty is that the portion put in freehand and that put in on the printing press always differ in appearance. To overcome this defect, a rubber stamp may be used to do the printed part and then the draftsman can go over it with ink. Or a copy may be made and slipped under the tracing cloth, as a guide to aid in securing speed and uniformity in size and style.



## CHAPTER IV

### USE AND CARE OF INSTRUMENTS

The purpose of a drawing course is two-fold: it aims first to give the student an understanding of the principles upon which drawing is based, and second, to give him instruction and practice in the use of his instruments, so that he may acquire a workmanlike facility in their manipulation. The instruments may be used in a variety of ways, — good, bad, and indifferent — and results of a corresponding kind produced. The engineer's object is not to produce something that will just "get by," but rather to secure the best results from the standpoint of appearance and accuracy, in the least possible time.

Speed, accuracy, and neatness are largely matters of proper habit. Correct habits may be just as easily acquired as slovenly habits, by learning the proper form at the beginning. As the athlete who runs or jumps "in poor form" has very little chance of winning because he must put forth a much greater effort than the man who works "in form," just so the draftsman who violates the rules of proper form, simple and almost trivial though they seem, can achieve success in the use of his instruments only by a much greater expenditure of time and energy than would otherwise be necessary. By the word *instruments* we mean all the equipment in the draftsman's kit, including pencils, erasers, scales, etc.

To learn the correct *form* of handling instruments, one should study the proper *use* of the instruments in order that awkward and useless movements may be eliminated and inaccurate methods avoided.

**PENCILS.** — Drawing pencils may be obtained in seventeen degrees of hardness, varying from 6B, the softest and blackest, to 9H, the hardest. The proper grade to be used depends upon the kind of work to be done and the quality of paper employed. For all-round usefulness the 4H pencil is perhaps the best, although for very accurate work, the harder grades should be used, while for sketching and lettering the softer grades are desirable. For general mechanical drawing the 5H pencil is recommended for laying

out the work on Normal or other good detail paper. A 3 pencil may be used for finishing the drawing and for the lettering.

More important, however, than the quality of the pencil is the condition in which it is kept. The proper shape for a pencil point is shown in Fig. 1. The tapered wood portion should be about seven-eighths of an inch long, and three-eighths of an inch of lead

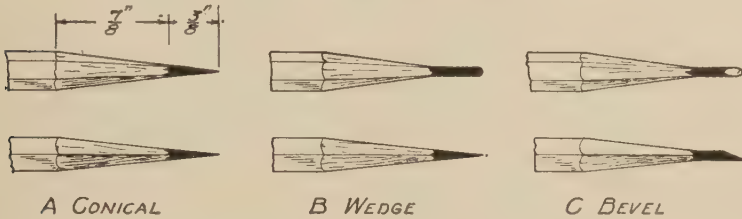


FIG. 1. Correct shapes of pencil points.

should be exposed. The lead should be brought to a point by means of a file or sand-paper. For a conical point, as in A, Fig. 1, the pencil should be rotated slowly while it is rubbed back and forth. The pencil should be kept inclined to the direction of motion, not at right angles to it. To produce the wedge point, as in B, Fig. 1, the opposite sides of the lead must be rubbed down. The bevel point, C, is made by rubbing entirely on one side.

The wedge point is used for drawing long straight lines, since it does not wear down so rapidly; its use, however, is limited to straight lines. The conical point may be used for all general drafting purposes and should always be used for lettering, for which it is particularly adapted. The bevel point is recommended for use in the compass, as it has the same advantages there as the wedge point has for straight lines. When the point is inserted in the compass, the beveled face should be turned directly toward the needle point. Since the ordinary drawing pencil wears away rapidly, the sandpaper or file should always be kept handy to resharpen the lead.

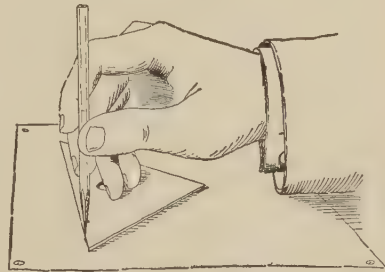


FIG. 2. Correct method of holding pencil against T-square or triangle edges.

In drawing a straight line, the pencil should be held in a plane perpendicular to the paper along the edge of the T-square or triangle, and should be slightly inclined in the direction of motion. See Fig. 2. Note that the pencil is held in a little different manner from that used in writing or lettering. The pencil should not be allowed to rock back and forth transversely to the direction of motion. Just enough pressure should be applied to the pencil to make a firm, light line that can be readily seen, but not enough pressure to make a groove in the paper, as a groove cannot be erased and spoils the appearance of a drawing. The importance of clean-cut pencil work cannot be overemphasized; it tends toward both speed and accuracy in tracing. A careless pencil job is difficult to improve either in inking or tracing.

**ERASER.** — Only a pencil eraser and art gum are necessary in mechanical drawing. Their purpose is, of course, to remove lines drawn in error, and hence the less the eraser has to be used the better. On tracings, the pencil eraser should be used to remove ink lines. A little more rubbing is required than with erasers containing grit, but the tracing is left in good condition for inking over the erased spot. An ink eraser or knife should not be used. The erasing shield is quite convenient in protecting lines which are not to be removed and should be used where occasion demands. The art gum is used to clean the sheet, but it is much better policy to keep the drawing as clean as possible and not depend on art gum to remove the dirt.

**LETTERING PENS.** — See Chapter II.

**DRAWING BOARD.** — The drawing board should be made of soft white pine or basswood, with properly cleated ends. It should be perfectly flat, free from cracks, and have one end edge straight. The true edge should be determined with some reliable straight edge, marked when found, and thereafter always used as the left hand edge. The top and bottom edges of the board need not be at right angles to the edge selected, and as a matter of fact they seldom are; nor is the right edge often exactly parallel to the left. The board should not be used for cutting purposes as this practice destroys the drawing surface in a short time. When it is possible to do so, the board should be so placed that the light comes from the left and front. This obviates annoying shadows.

**T-SQUARE.** — The common T-square consists of two parts, the blade and the head, which should be rigidly fastened together. A variety of kinds and sizes may be obtained from the trade, a few of

which are shown in Fig. 3. Different lengths may be obtained, ranging from 18" to 72". The upper edge of the blade and the inner edge of the head should be perfectly straight. Both parts should be made of hard wood, but a celluloid edge on the blade is desirable for the sake of transparency. The accuracy of the T-square blade may be tested by drawing a straight line between two points and then turning the blade over and drawing the same line again, using the

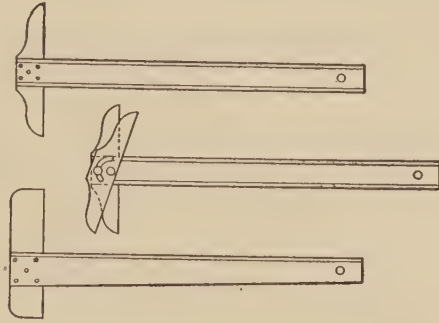


FIG. 3. T-squares.

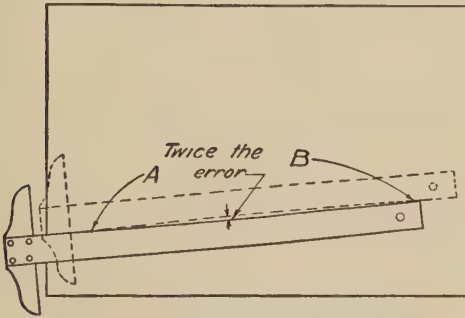


FIG. 4. Testing T-square edge.

guide for the knife in cutting paper.

The purposes of the T-square are, first, to draw horizontal lines, and second, to serve as a support for the triangles when vertical and diagonal lines are being drawn. The head of the T-square should be held to the board with the left hand and the line drawn with the right. Horizontal lines should always be drawn from left to right. One should not stroke back over an ink line, for the result is usually a line of varying width and represents a waste of time in any event. Only the upper edge

same edge as before, as shown in Fig. 4. If the two lines coincide the blade is true. To keep the T-square in good condition, careful handling is required. It should not be used as a hammer nor allowed to drop on the floor. The upper, or drawing, edge should not be used as a

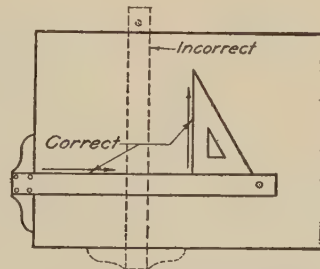


FIG. 5. - Ruling horizontal and vertical lines.



of the blade should be used for drawing, because the lower edge is not necessarily parallel to the upper edge; hence, inaccuracy may result if it is used. The T-square should not be used to draw vertical lines, as shown in Fig. 5, because the two edges of the board may not be at right angles to each other. To draw any line

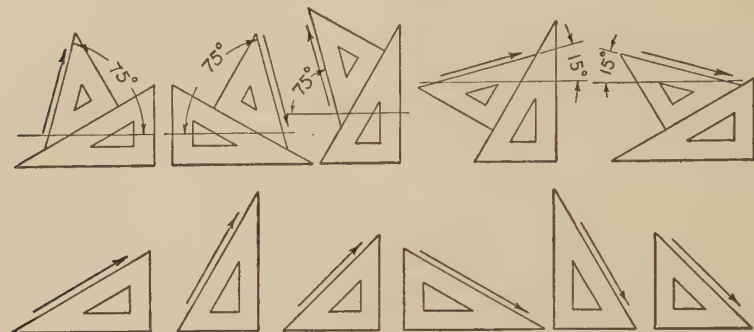


FIG. 6. Direction of motion in ruling sloping lines.

longer than the triangles will accommodate, whether vertical or otherwise, locate the line by two points and then turn the T-square over and draw the line, using the proper edge of the T-square. When drawing vertical lines, which should be drawn from the bottom toward the top, the triangle should be turned with the vertical edge to the left and held against the T-square, as shown in Fig. 5.

**TRIANGLES.** — The 30-60 degree triangle and the 45 degree triangle are used not only to draw vertical lines but also lines making

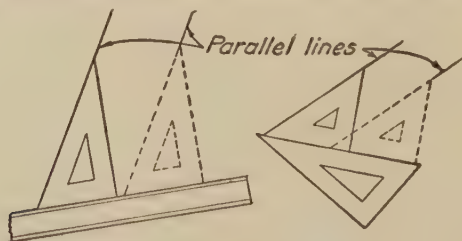


FIG. 7. Drawing parallel lines.

angles of 30, 60, 45, 15, and 75 degrees with the horizontal or vertical. The proper combinations for drawing the last two angles are shown in Fig. 6. It is frequently necessary to draw a line parallel to another line which does not make any of the above angles with the horizontal. The proper method for drawing such a line is

shown in Fig. 7. Two lines may be drawn perpendicular to each other by means of two triangles, or a T-square and a triangle, as shown in Fig. 8. In drawing any line, the direction of motion should, in general, be away from the body and not toward it. The accuracy of the 90 degree angle of any triangle may be tested as shown in Fig. 9.

**PAPER.** — Commercial practice varies considerably in the use of drawing paper. Some shops use standard sheets which are obtained already cut to size, while others use paper from the roll, the draftsman cutting off what he needs each time. The same practice holds for tracing cloth.

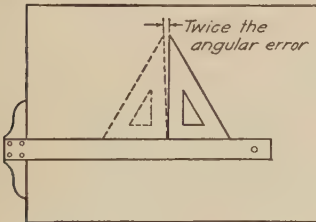


FIG. 9. Testing the triangle.

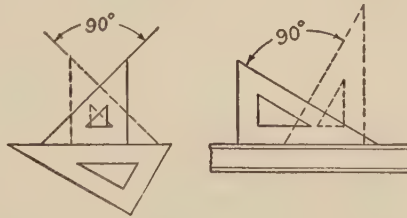


FIG. 8. Drawing perpendicular lines.

The sheets may be obtained not only cut to size but also having the border line and a standard title form printed on them. The common standard sizes for paper and cloth are  $9 \times 12$ ,  $12 \times 18$ ,  $18 \times 24$ ,  $24 \times 36$ , and  $36 \times 42$ . The sizes for hot and cold pressed, hand-made papers vary from those given above, but they are seldom used by engineers except in architectural work. The name of each size is given below.

|             |                |                      |                |
|-------------|----------------|----------------------|----------------|
| Cap.....    | $13 \times 17$ | Super Royal.....     | $19 \times 27$ |
| Demy.....   | $15 \times 20$ | Imperial.....        | $22 \times 30$ |
| Medium..... | $17 \times 22$ | Double Elephant..... | $27 \times 30$ |
| Royal.....  | $19 \times 24$ | Antiquarian.....     | $31 \times 53$ |

Hot pressed paper, designated simply H. P., has a smooth surface and is used mostly for ink work, such as fine mechanical drawings. Cold pressed paper, C. P., is fine-grained and is used chiefly for general pencil drawing and water color painting. The quality of paper designated "rough" or "egg-shell" has, as its name signifies, a rough surface and is used principally for bold pencil drawings, charcoal work, and water-color sketches.

Where standard size sheets are used, the space to be included inside the border line is known to begin with. Hence, to lay out the border lines, place the sheet at a convenient position on the

drawing board and put a thumb tack through the upper left-hand corner. Then rotate the sheet until its upper or lower edge is in contact with the upper edge of the T-square. When in this

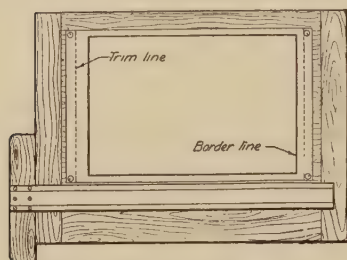


FIG. 10. Layout of sheet.

position, put a thumb tack through the upper right-hand corner and then tack the remaining corners down, taking care to have the sheet stretched out smoothly. The border lines may then be laid out by measurement from the edges of the sheet, or from its horizontal and vertical center lines if the edges are not at right angles to each other or are cut

unevenly. The thumb tacks should be pushed down as far as they will go so that the T-square and triangles may slide over them readily. Figure 10 shows a standard sheet layout with trim lines and border lines indicated. When the paper is trimmed, the thumb tack holes are, of course, removed

When standard size sheets are not used, the drawing is usually made first and the border line placed around it afterward.

**THUMB TACKS.** — Thumb tacks may be obtained from the trade in many styles and sizes. Cheap ones may be obtained in boxes of one hundred, for less than the price of a dozen good ones. The types shown in Fig. 11, *C* and *D*, will be found to give the greatest satisfaction, since they can be pushed down tight against the paper and then offer no obstacle to the movement of the T-square and triangles. They are worth several times their extra cost in the annoyance they prevent.

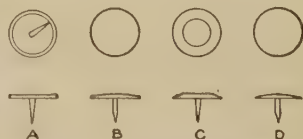


FIG. 11. Types of thumb tacks.

**SCALES.** — The size of the drawing papers upon which an engineer must work is quite limited, but the size of the object or project he may be required to draw may vary from a fraction of an inch to hundreds and thousands of feet in extent. As long as the object is considerably smaller than the convenient sizes of drafting paper, it may be drawn in its natural size. The drawing is then spoken of as a *full size drawing*. If the object is larger it may be drawn one-half size, that is, six inches on the drawing will represent one foot on the object. Likewise, it may be drawn one-quarter size,

which means that three inches on the drawing represents one foot on the object. In this way the size of the drawing may be greatly reduced. For one-half size drawings, the necessary reductions may be made mentally and laid off on the paper with a regular scale having one-sixteenth inch divisions. For the smaller sizes, however, time and effort can be saved by having scales made to represent the reduced dimensions. Three kinds of scales are in common use in this country, namely, the architect's, civil engineer's (or simply engineer's), and mechanical engineer's. They are made in both triangular and flat shapes, shown in Fig. 12, and contain the following divisions:



FIG. 12. Sections of standard scales.

| Architect's<br>Scale    | Mechanical Engineer's<br>Scale | Civil Engineer's<br>Scale |
|-------------------------|--------------------------------|---------------------------|
| 3 " equals 1'-0"        | $\frac{1}{8}" = 1"$            | 1" equals 10'-0"          |
| $1\frac{1}{2}"$ " 1'-0" | $\frac{1}{4}" = 1"$            | 1" " 20'-0"               |
| 1 " " 1'-0"             | $\frac{1}{2}" = 1"$            | 1" " 30'-0"               |
| $\frac{3}{4}"$ " 1'-0"  | 1" = 1"                        | 1" " 40'-0"               |
| $\frac{1}{2}"$ " 1'-0"  |                                | 1" " 50'-0"               |
| $\frac{3}{8}"$ " 1'-0"  |                                | 1" " 60'-0"               |
| $\frac{1}{4}"$ " 1'-0"  |                                |                           |
| $\frac{3}{16}"$ " 1'-0" |                                |                           |
| $\frac{1}{8}"$ " 1'-0"  |                                |                           |
| $\frac{3}{32}"$ " 1'-0" |                                |                           |
| 1 " " 0'-1"             |                                |                           |

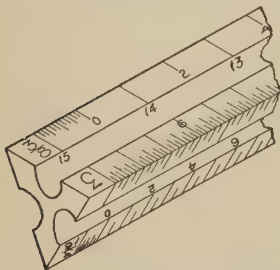


FIG. 13. Architect's scale.

On the architect's scale, the main divisions represent one foot, and hence the basic scaling divisions at each end of the rule are subdivided into twelve parts and fractions thereof, as in Fig. 13. The civil engineer's scale has the inch space subdivided into some multiple of ten; hence the main divisions represent 10 ft., 20 ft., etc., or 100 ft., and 200 ft., as conditions may require. On the mechanical engineer's scale the main divisions represent one inch, and the basic scaling divisions are then subdivided into halves, quarters, eighths, sixteenths, etc.

When it is necessary to lay off a large number of equal spaces



which must total a certain specified amount, the scale should be used, and not the dividers. The end of the scale should be made to coincide with the first mark on the paper and then all of the spaces should be laid off, if possible, without moving the scale. In this way, small discrepancies may occur in any one unit, but there will not be a cumulative error in the whole. When it is desired to divide a given space into an odd number of equal parts, as, for example, two inches into five parts, this should be done with the scale, as shown in Fig. 14.

To employ the scale properly, one should place the working edge farthest from him against the paper and then, looking down over

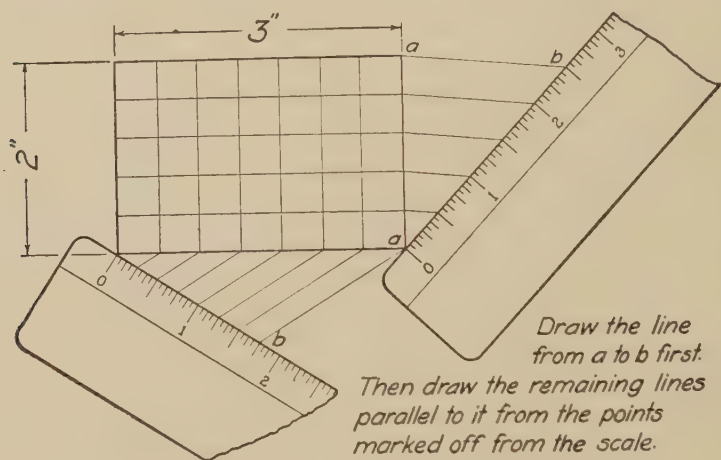


FIG. 14. Use of scale to divide a space into equal parts.

it, mark off the required dimensions with a conical-pointed pencil.

**INSTRUMENTS.** — A complete drafting equipment includes all of the foregoing items, and in addition a small box or case of drawing tools, usually referred to as a "set of instruments." A set of instruments should include the following pieces.

- 1 — 6" compass with interchangeable pencil, pen and needle points
- 1 — 6" hair spring divider
- 1 — Bow Pen
- 1 — Bow Pencil
- 1 — Bow Divider
- 1 — 6" Detail Pen
- 1 — 4" Ruling Pen
- 1 — Key or screw driver to adjust instruments
- 1 — Box of leads
- 1 — Lengthening bar for compass

This is the minimum acceptable as a complete set of instruments, but it includes everything a draftsman needs for ordinary work. Where special work requires other instruments, these are usually supplied by the concern for whom the draftsman works. Some of the more common special instruments are the drop pen, the contour pen, the parallel straight edge, the beam compass, the ellipsograph, the pantograph, the section liner, and the railroad curves or ship curves.

In selecting instruments, the chief point of consideration should be quality. An expert may produce satisfactory drawings with inferior instruments, but the beginner will find his task sufficiently difficult without the handicap of poor equipment. Unfortunately, to all outward appearances, good instruments and poor instruments may look quite alike, so that it is best to secure the advice of an experienced man before making a purchase. For the student who expects to follow the engineering profession, it is good economy to spend a few extra dollars for a high-grade set which will last a lifetime, rather than save the money and endure the annoyance of loose joints, broken parts, and rusted or stripped threads, which so frequently occur with cheap instruments. In any event, the draftsman should not purchase materials which do not have the manufacturer's or dealer's name or trade mark stamped on each piece.

The following paragraphs make clear the proper methods for handling the various pieces of a set of instruments. The use to which they are subjected and the care they receive when not in use determine to a large extent how long they will last.

**DIVIDERS.** — The dividers are used chiefly for transferring measurements and for dividing spaces into equal parts. To set the divider, it should be held as shown in Fig. 15. The second and third fingers are

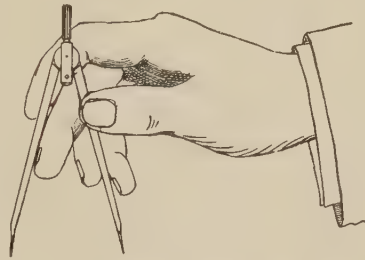


FIG. 15. Correct holding of divider.

placed inside to help control the movement of the points, when the distance to be set permits. When the space to be set is small, the divider must first be opened wider than the space and then closed down to the proper measurement by pressure from the thumb and fingers. The divider may be set directly from the

scale, by setting one point very lightly at the top of one of the division marks and then bringing the other point to the proper place without sticking it into the wood. This practice, of course, destroys the marks on the scale; but with ordinary care it will be worn out from other causes long before the prick marks from the dividers have materially affected it.

To step off distances, grasp the knurled top of the divider between the thumb and first finger, and rotate first in one direction and then in the other. This avoids taking a new hold on the instrument which would be necessary if it were always turned in the same direction. The points of the instrument should not be pushed through the paper, but instead only small dents need be made. These may be identified by making small rings around them free-hand, after which they can always be found. The divider points should be kept sharp and of the same length; they should not be stuck in the drawing board when not in use.

**RULING PEN.** — The ruling pen should be held in the same manner as the drawing pencil, that is, slightly inclined in the direction

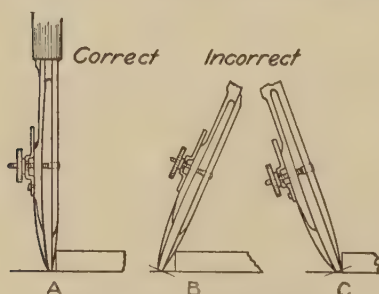


FIG. 16. Common positions of ruling pen.

of motion in a plane perpendicular to the paper through the line being drawn. Great care must be exercised to get and keep the correct position of the pen, since only a slight deviation is necessary to bring disastrous results. Figure 16 shows the right and wrong relation between the ruling pen and the triangle or T-square.

The two ruling parts of the pen are called *nibs*, and from the figure it is clear that both nibs must touch the paper. The bevel of the nibs keeps the point away from the triangle when properly held. If the pen is held as in *B*, Fig. 16, a ragged line results, while if held as in *C*, Fig. 16, the ink will run under the triangle.

The small bottles of ink are supplied with a quill which is fastened in the cork. The ruling pen should be filled by placing the quill between the nibs and allowing the ink to run into the pen. The ink should not stand higher than one-fourth of an inch in the pen, as the weight of a higher column will frequently cause it to run out and make a blot the moment the pen is touched to the paper.

In the better sets of instruments, the pens are ground and polished ready for use. Sometimes, however, the nibs are not properly pointed, and, of course, well-pointed nibs will in time wear down, so every draftsman should know how to sharpen his pen. Figure 17 shows how the nibs usually wear and how they should appear when in proper condition.

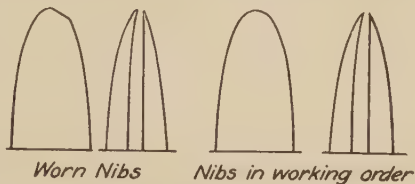


FIG. 17. Nibs of ruling pen.

The first operation in preparing the nibs for use consists of grinding them to an even length and then rounding them off so that the end has the shape of a parabola, as shown in the figure. This can be done by closing the pen and then rubbing the nibs over an oil stone, keeping the pen in a plane perpendicular to the surface of the stone and rocking it back and forth in the direction of motion as the grinding proceeds. The next operation is that of sharpening the nibs. This must be done by grinding entirely from the outside, until the edges of the nibs do not show any flat shiny spots when viewed edgewise. Care should be exercised in this operation to see that the nibs are not again made unequal in length, and also to avoid making them so sharp that they will cut the paper.

Faulty lines always reflect upon the draftsman, for either he does not know how to keep his pen in order or else he does not know how to use it when it is in order. Long lines should always be drawn with an arm movement, coming almost to rest near the end and finishing with a finger movement. Short lines, of course, are always drawn with finger movement. The pressure upon the paper should be but little more than the natural weight of the pen. Additional pressure serves only to tire the arm and fingers and groove the paper, with no corresponding improvement in the flow of ink. Likewise, the side pressure upon the T-square or triangle should be just enough to ensure a firm and continuous contact.

In inking straight lines and curves that join each other, the curve should be inked first and great care taken to stop the arc exactly at the tangent point as shown in Fig. 18. The ruling pen should then be lined up with the end of the arc, as shown in the figure, before actually touching it to the paper.

One of the common faults of beginners is that of running the lines beyond their proper stopping points. It should be remem-

bered that the ink flows just a little ahead of the pen; therefore, when the line being drawn is to end upon another line, the pen must be stopped at the near side of the line. A little practice on scratch paper will enable the draftsman to determine just when to stop his pen to avoid over-running. Drawing ink dries quite rapidly and forms little cakes on the inside of the nibs; therefore, the

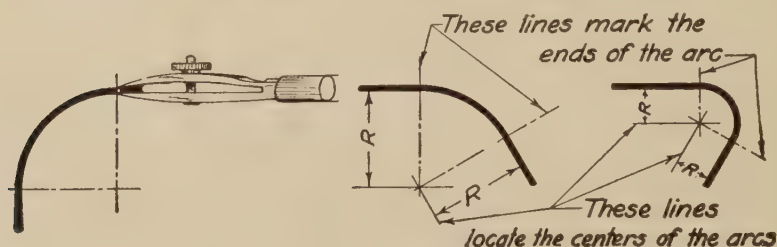


FIG. 18. Joining arcs and straight lines.

pen must be frequently cleaned while in use, and it should always be cleaned before it is put away. A clogged pen is one of the most common causes of poor lines. Another cause of poor lines is the presence of lint, dust, and dirt on the paper. The ruling pen will pick these up and cause a sudden widening of the line.

If a pen is in proper working order and is properly held, it is almost certain to produce a good line, except on tracing cloth, where

*BORDER LINES*

*VISIBLE OUTLINES*

*INVISIBLE OUTLINES*

*CENTER LINES*

*DIMENSION LINES,  
AUXILIARY, EXTENSION,  
OR WITNESS LINES, &  
CROSS SECTION LINES*

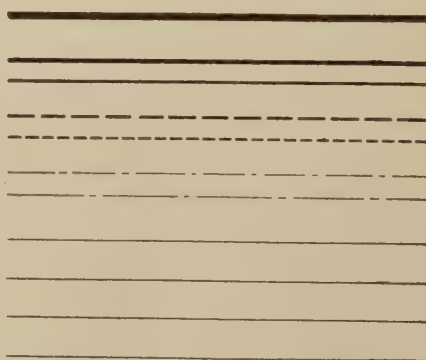


FIG. 19. Proper weight of ink lines.

a slightly oily surface may give trouble. This may be overcome by rubbing the surface with magnesium carbonate and then wiping it clean with a cloth. Avoid touching the tracing cloth with the



hands any more than is necessary, for the hands may leave traces of oil on its surface.

In order to make a drawing give the feeling of "life and vigor," there must be a variation in the weight of the different lines employed. The outline of an object should stand out sharply, with the hidden lines somewhat less prominent. Dimension lines, auxiliary lines, and center lines should be still lighter. Figure 19 shows the proper weight for the various kinds of lines. These weights of lines should be learned through diligent practice.

**COMPASS.** — The compass should be adjusted before it is used for the first time, and then maintained in this condition. One leg is arranged to hold either a lead or a pen. The pen is put into the compass, and then the needle point is adjusted so that it is about one thirty-second of an inch longer than the pen. Thus, when the point sinks into the paper the pen will be perpendicular to the paper and just touch it, when the compass is held in a vertical position. The needle point, once adjusted, should not be changed again for the lead points; instead, the lead points should be made to suit the needle point. In this way the compass can be quickly changed from pencil to ink work. The lead for the com-

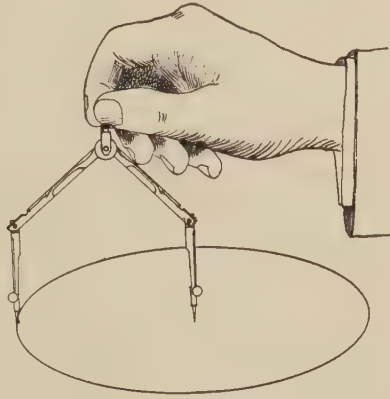


FIG. 20. Correct position of compass legs.

pass should be as hard as the drawing pencil and should be sharpened to a wedge or bevel point, and kept sharp just as is the drawing pencil. For small circles, the legs of the compass may be kept straight, but for the larger ones both legs should be bent as in Fig. 20, in order that the pen may be perpendicular to and have both its nibs touching the paper. The center is also perpendicular to the paper; and in this position it will not wear a large unsightly hole, as would be the case otherwise if several concentric circles were to be drawn. It is best in drawing circles to move the pen clockwise and to go around the circle only once. The line should not be gone over a second time in either direction.

**BOW INSTRUMENTS.** — The bow instruments are used for making small circles and arcs. The general directions given above for the large compass apply equally to the bow instruments. In addition to following the previous instructions, it is well, in setting the bow instruments to any given dimension, to relieve the pressure of the spring by pinching the points together in order to reduce the wear on the thread. This applies to side adjustment instruments only.

**IRREGULAR CURVE.** — This instrument, which is sometimes called a French curve, is one of the most difficult to use skillfully, especially when doing ink work. The skill required lies chiefly in the handling of the pen, but also to a considerable extent in the placing of the curve. If the curve is to be drawn through a series



FIG. 21. Proper use of irregular curves.

of points, as is usually the case, the irregular curve should be made to fit as many of the points as possible at one time. This fitting of the curve to the points must be accomplished by trial. In no case should a line be drawn when the curve does not fit at least three points and have the proper curvature toward the next points on both sides. Figure 21 shows how the curve may be set several times to complete one curved line.

**EXERCISES.** — Facility in the use of instruments can only be acquired by practice. The Geometrical Constructions shown in the Appendix furnish excellent exercises for practice.

## CHAPTER V

### ORTHOGRAPHIC PROJECTION

**ELEMENTS OF PROJECTION.** — There are three major kinds of projection, namely, Orthographic, Oblique and Perspective. In discussing any one of them, four distinct elements must be considered. These elements are the projecting lines, the point of sight, the surface upon which the projection or drawing is made, and finally, the object itself. No real understanding of the theory of projection can be had without considering the fullest relation-

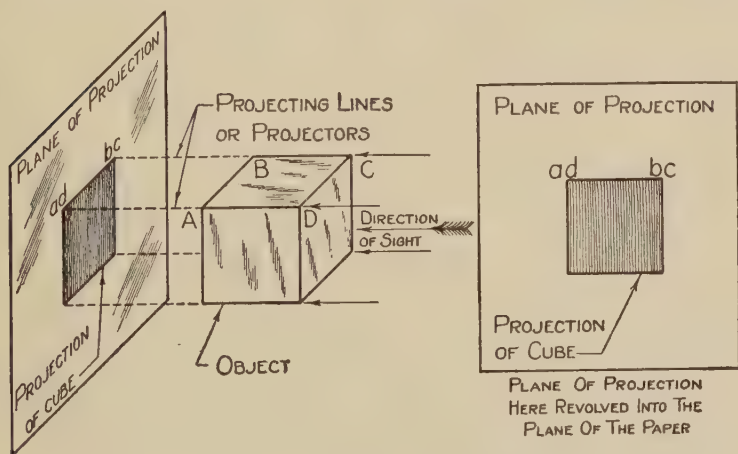


FIG. 1. One plane of projection.

ships of these four factors. They are so closely interrelated that a discussion of one of them must necessarily involve the others; hence, any treatment of a single item should not be considered as complete until all four have been finished in turn. A study of Fig. 1 will give a general idea of the meaning of these four elements which may be briefly defined as follows:

Projecting Lines are the imaginary lines along which points are projected from the object of which they are a part, to the surface on which the drawing is made.

The Point of Sight is the real or imaginary position of the observer from which the projection or view is obtained.

The Plane of Projection is the plane surface upon which the object is projected or drawn.

The Object may be anything real or imaginary which it is desired to represent.

**THEORY OF PROJECTION.** — The projection of any point of an object on a plane of projection is the point (projection) in the plane of projection where the projecting line through the given point pierces the plane. Thus, in the first drawing of Fig. 1, the projection of corner *A* of the cube is at *a* in the plane of projection. Similarly, the projection of the edge *AB* of the cube is the line *ab* in the plane of projection. The projection of the face *ABCD* is the line *ab* or *dc*. Hence, the projection of any object may be obtained by getting the projections of all of its outstanding or bounding points and lines.

The appearance of the projection of an object will depend upon the relation to each other of the four items mentioned above, most important of which is the relation of the projecting lines to the plane of projection.

**PROJECTING LINES.** — Three possible situations may arise in the relation of projecting lines to the plane of projection as illustrated in Fig. 2. In the first drawing of Fig. 2, the projectors

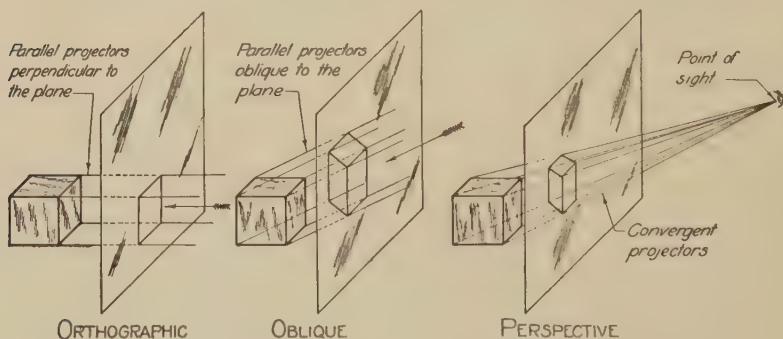


FIG. 2. Projectors or lines of sight.

are parallel to each other and perpendicular to the plane of projection. Projections made upon this basis are called Orthographic Projections. Orthographic Projection may be defined, therefore, as any projection made upon the theory that the projecting lines are perpendicular to the plane of projection. This is the kind of

projection with which this chapter is concerned. An important division of orthographic projection, called Isometric Projection, is treated in considerable detail in Chapter XI.

The second illustration of Fig. 2 shows parallel projecting lines which are oblique to the plane of projection. Projections made upon this basis are called Oblique Projections. The last drawing of the figure shows convergent projecting lines which necessarily make different angles with the plane of projection, unless there are one or more planes of symmetry in the whole projective system. This type of projection is called Scenographic Projection or Perspective.

**POINT OF SIGHT.** — While it may be possible to think of projections as being made by mechanical projecting lines which fulfill certain geometrical conditions, useful drawings cannot be made without a definite conception of a point of sight and of its location. The relation of the projecting lines to each other may be said to depend upon the location of the point of sight, which may be assumed in either of two general positions. It may be at an infinite distance from the object or at a finite distance from it. If the point of sight is at infinity, the projecting lines must, as a result, be parallel to each other, as in the first and second drawings of Fig. 2; whereas, if the point of sight has a finite location, the projecting lines converge to this point as in the third drawing of Fig. 2.

**PLANES OF PROJECTION.** — Drawings may be made upon any kind of surface, as, for example, the paintings upon the curved walls and domes of cathedrals and other public buildings. The engineer's drawings, however, are always conceived as projected upon a plane surface. Such a plane is called a plane of projection. See Fig. 1. In the imagination, the plane is conceived to be transparent, although, as a matter of fact, it is represented by the sheet of paper, or tracing cloth, upon which the drawing is made.

For use in actual construction, a projection upon a single plane (isometric and oblique drawing excepted in simple cases) is found to be inadequate. Referring again to Fig. 1, it will be noted that the length of  $AD$ , the dimension of the cube which is perpendicular to the plane of projection, is not shown by the projection of  $AD$  at all. If one did not know the object to be a cube, either from a note on the drawing or from previous knowledge, no idea of the length of the object would be conveyed by the drawing.

Since in construction work previous knowledge certainly cannot



be assumed, and since notes on a drawing may be overlooked and would in themselves be inadequate for most objects, two planes of projection at right angles to each other form the minimum basis for all engineering drawings of this type. Figure 3 represents two

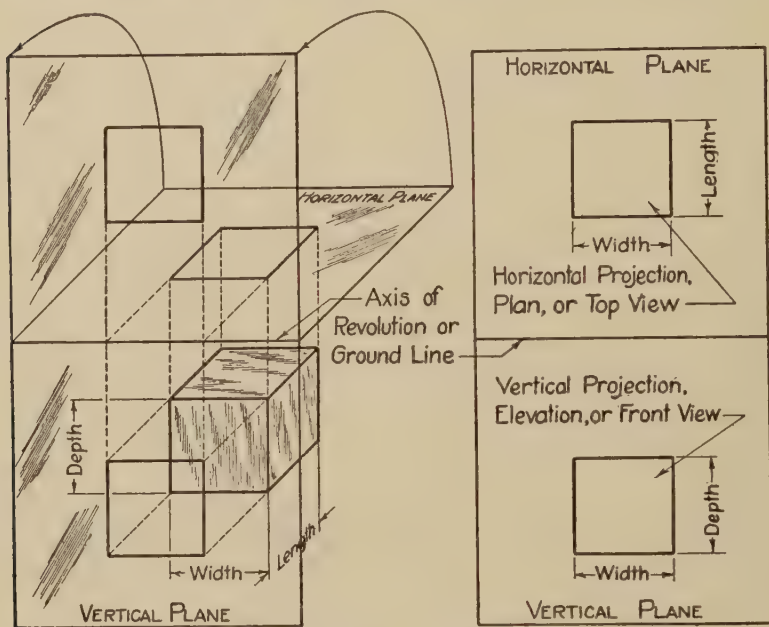


FIG. 3. Two planes of projection.

such planes of projection at right angles to each other. One of the planes is always assumed to be horizontal and the other vertical. They are designated by these names as shown in the figure.

The three dimensions of the cube in Fig. 3 have been designated as the length, width and depth. It will be noted that the projection on the vertical plane, called the elevation or front view, shows the width and depth of the object, while the horizontal projection, called the plan or top view, shows the width and length. These two views thus give all necessary information as to the shape of this simple object.

While two projections like those of Fig. 3 suffice to give the shape and size of most three dimensional objects, it frequently happens that even they fall short of giving complete information. A careful examination of the pictorial sketch and the corresponding

orthographic projections of Fig. 4 will show that three views are necessary to describe the shape of this object completely. In order to obtain three views, a third plane, called a profile plane, is set up perpendicular to the other two.

The three planes of projection which we have just shown to be necessary are often called the Coördinate or the Principal Planes of Projection. For brevity in discussion and illustration, these planes are designated by the initial letter of the word which

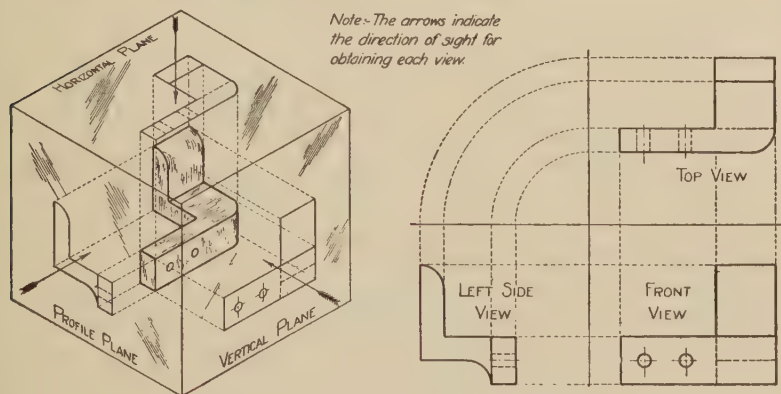


FIG. 4. Three planes of projection.

describes them. Thus, the vertical plane is called the V-plane, the horizontal plane is called the H-plane, and the profile plane is called the P-plane, or simply V, H and P.

**ROTATION OF THE COÖRDINATE PLANES.** — Drawings, whether composed of one, two, three, or more views are always shown on a single plane surface, namely, the sheet of drawing paper. The transformation from three planes at right angles to each other, illustrated in Figs. 3 and 4, to a single plane may be readily accomplished by imagining the vertical plane to remain fixed while the others are revolved into coincidence with it. Each plane is revolved away from the object about its line of intersection with the V-plane as an axis, as shown in Fig. 5. From this figure it can be seen that where there are more than two views required the bottom part of a drawing sheet will be somewhat crowded, particularly if there are several objects drawn on the same sheet. This condition is accentuated by the fact that the title is almost invariably placed in the lower right-hand corner of the sheet.

To overcome this situation an alternate method of rotating the planes may be adopted. Thus, in Fig. 6, the profile plane or planes are first rotated about their line of intersection with the H-plane into coincidence with it, after which the H-plane is rotated in the usual way. This arrangement transfers the crowd-

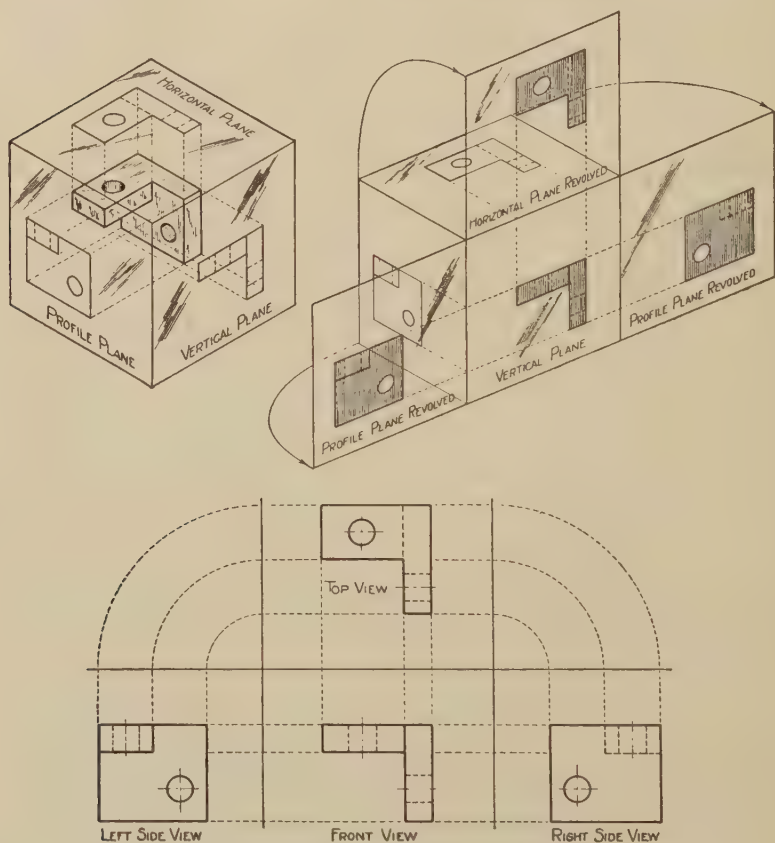


FIG. 5. Revolution of coordinate planes, (standard method).

ing from the bottom to the top of the sheet but to a less degree. By a proper combination of the two methods, a drawing sheet may be nicely balanced. Where there is no specific reason for doing otherwise, the first method of revolution, illustrated in Fig. 5, is to be preferred.

It should be carefully observed that the process of revolution of the coordinate planes brings the various views of an object into a

very definite relationship to each other. The views are said to be "in projection" with each other. The position of the views depends upon the method of rotation; but, since the horizontal plane is always turned the same way, the top and front views are

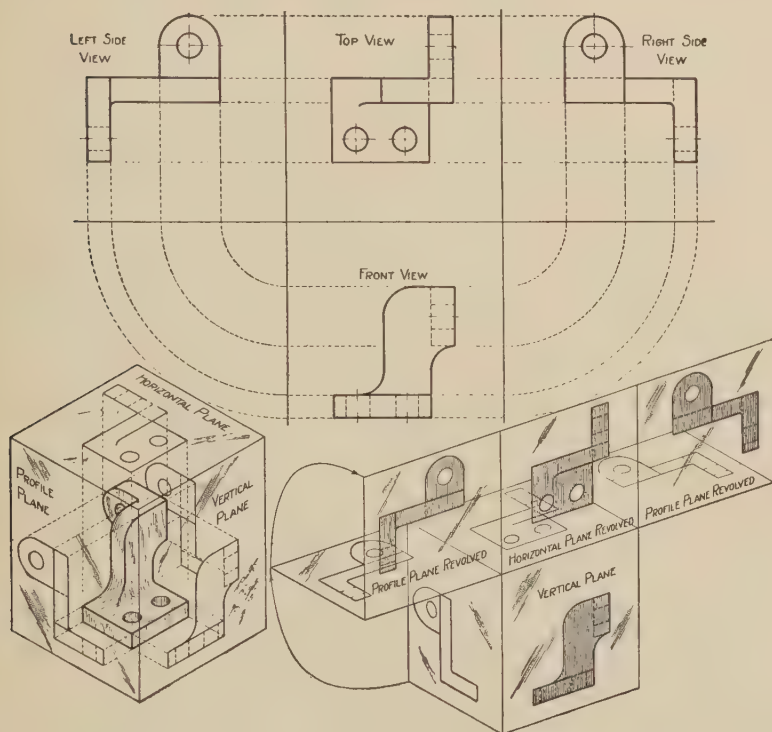


FIG. 6. Revolution of coördinate planes, (alternate method.)

always in alignment vertically. When the imaginary rotation is performed, as in Fig. 5, the profile and front views will come into horizontal alignment; whereas, when the rotation is performed as in Fig. 6, the top and profile views come into horizontal alignment. No departure from the arrangement of views shown in these two figures can be tolerated, for otherwise the drawing becomes unintelligible to every one save the draftsman who made it.

Three mechanical schemes for constructing the third view from the other two are shown in Fig. 7. On working drawings, the lines which represent the axes about which the planes have been

revolved, usually called ground lines, are erased when the views have been completed; or the views themselves are constructed

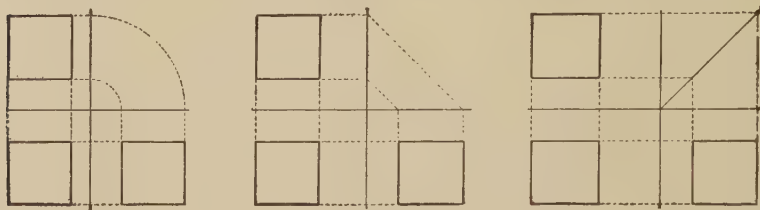


FIG. 7. Mechanical methods of transferring distances.

without the aid of ground lines by projecting from one view to another and transferring the measurements with the scale or dividers. Thus, the right side view in Fig. 8 has been constructed by projecting horizontally from the front view and transferring the dimensions  $a$ ,  $b$  and  $c$ , from the top view as indicated. It should be noted that every point, line or plane on an object is represented in every view that is made of it. The draftsman must be able

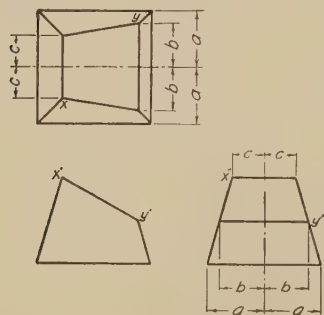


FIG. 8. Scale method of transferring distances.

to identify these representations in all of the views.

### DIHEDRAL ANGLES OR QUADRANTS.

The illustrations of this chapter have for convenience and of necessity shown the planes of projection as limited in extent, but they are really infinite or unlimited in extent. A plane is not limited by its intersection with other planes but may extend on through them as shown in Fig. 9. The horizontal and vertical planes divide all space into four equal parts called dihedral angles or quadrants. In referring to these angles it is understood that the

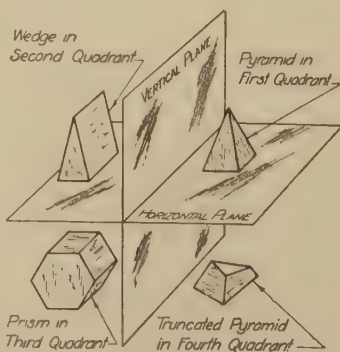


FIG. 9. Dihedral angles or quadrants.



observer's point of sight is always in front of the vertical plane and above the horizontal plane. That portion of space in front of the vertical plane and above the horizontal plane is called the first angle or quadrant; that portion of space behind the vertical plane and above the horizontal is called the second angle or quadrant; that portion behind the vertical and below the horizontal, the third angle or quadrant; and that in front of the vertical and below the horizontal, the fourth angle or quadrant. See Fig. 9. Setting up the third coördinate or profile plane does not in any way change the quadrants or limit their extent.

**CHOICE OF QUADRANTS.** — From Fig. 9 it may be seen that an object can be placed in any one of the four quadrants and then projected upon the three coördinate planes. For certain reasons,

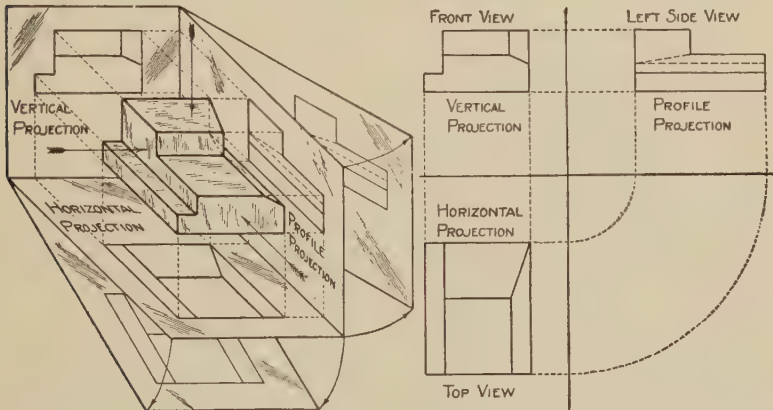


FIG. 10. First angle projection.

the portion of the horizontal plane in front of the vertical is always turned down and the portion in back of the vertical must, consequently, be turned up as has been indicated in Figs. 3, 5 and 6. With this direction of rotation of the H-plane definitely fixed, the second and fourth quadrants are immediately eliminated from consideration, since the horizontal and vertical projections would overlap each other and be useless.

If the first quadrant is used and the planes are rotated according to the rules already established, then the arrangement of views shown in Fig. 10 must result. The point of sight for the profile view is taken to the left of the object, in this case, on the basis that the object is always between the point of sight and the plane of

projection in the first quadrant. Had the profile plane been placed on the left side of the object, the point of sight would have been taken to the right of the object.

The objection to the result obtained from first quadrant projection is the unnatural arrangement of views, particularly of the front and top views. In looking at most objects which the draftsman must represent, the eye is usually above the object so that the top is seen above the front, which is just the opposite of the arrangement given by a first quadrant projection. This unnatural arrangement of views is the only objection to the first quadrant, but it is sufficient to have eliminated its use entirely in the United States, except for a few special kinds of drawing.

If an object is placed in the third quadrant and the rules for rotating planes are observed, a natural and pleasing arrangement of views follows, as may be seen from Figs. 4, 5 and 6. In this quadrant the top view of an object appears above the front as it should, and the right side view appears at the right as it should, without doing violence to the logical arrangement of object, point of sight, and plane of projection. It will be noted that in the third quadrant the plane of projection is always between the point of sight and the object.

**POSITION OF THE OBJECT.** — In the preceding discussion, it will be noted that while an object is frequently mentioned and used in the illustrations, the theory of projection developed is entirely independent of the shape of the object and its location in space. This is true so long as theoretical projections are the chief concern, but if useful drawings are to be made, the position of the object relative to the plane of projection is of great importance. A comparison of Fig. 11 with Fig. 1 serves to show that the position of the object makes a difference, not only in the appearance but also in the usefulness of the views. The projection of Fig. 1 shows the true size and shape of the cube while that of Fig. 11 shows only the width of the cube. From observation and from geometry it is known that the true value of the angles between lines, or the true length of lines, shows in projection when the lines themselves are parallel to the plane of projection. It may be stated, therefore, as a definite rule that, for engineering working drawings, the principal faces of the object should be placed parallel to the planes of projection. All of the figures of this chapter except Fig. 11 comply with this rule.

In the shop or factory or in nature we are accustomed to see

objects in certain definite positions and when we see them upside down, inside out, or in other unusual positions; they are quite unfamiliar. What is true of the objects themselves is equally true

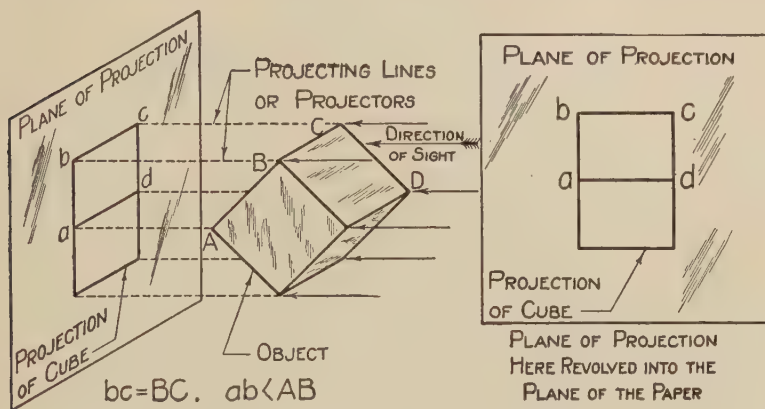


FIG. 11. Effect of position of object on projections.

of the drawings of the objects; hence, it may be stated, as a second definite rule, that objects should be placed and drawn in their normal or natural position or as near thereto as possible. Figure 12 represents a bearing cap which may be seen either on the top,

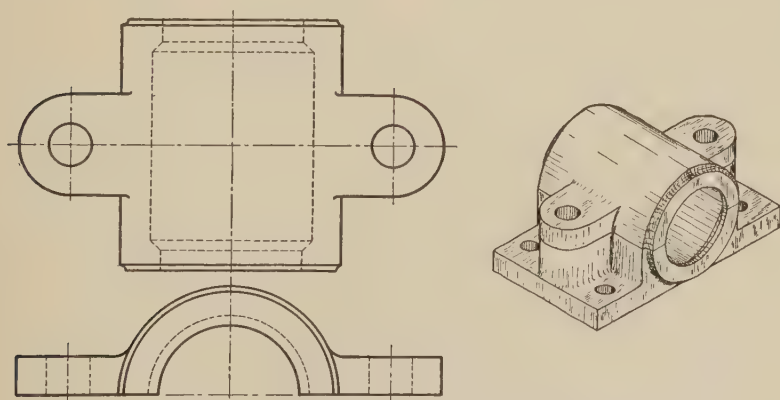


FIG. 12. Object drawn in natural position.

side, or bottom of a bearing, depending upon the position of the bearing as a whole, but, in any event, it is normally viewed from the outside and should be drawn as shown in the figure.

**INVISIBLE LINES.** — Regardless of how the object is placed or where the point of sight is selected, there will always remain, on even comparatively simple objects, certain lines which cannot be seen except by imagination. Although they are not visible to the observer, such lines must be shown in a drawing in order to portray accurately the shape of the object. Moreover they must be distinguished from the visible outlines in some way. This is accomplished by using a different type of line to represent the hidden edges. A dash line is universally used for this purpose. Examples of its use may be found in many of the figures of this chapter. The length and weight of the hidden lines to be used on a drawing are shown in Fig. 19 of Chapter IV.

When the number of invisible or hidden lines on a drawing becomes too great, they are difficult to interpret. It is, therefore, highly desirable that the projections be selected with a view to reducing the number of hidden lines to a minimum without, of course, turning the object out of its natural position. For example, in the object shown in Fig. 5, only three of the four views are actually required. Either the left or right side view can be chosen with the top and front view. In this case, the left side view is better since it has the fewer number of invisible lines and in all other respects is as good as the right side view. The same is true in the case of Fig. 6.

## CHAPTER VI

### AUXILIARY AND SECTION PLANES

The three principal planes of projection described in the preceding chapter prove inadequate when complicated machines, irregular castings, and various other objects are being represented. The chief reason for this lies in the fact that many objects with which the draftsman has to deal have important characteristics of form which do not show in true size or shape on any of the principal coördinate planes. It is clear, upon a moment's reflection, that only those lines and geometrical figures which are parallel to the principal planes show in true size upon them. It is, therefore, frequently necessary to set up one or more planes of projection in addition to the principal coördinate planes. These planes are called Auxiliary and Section Planes.

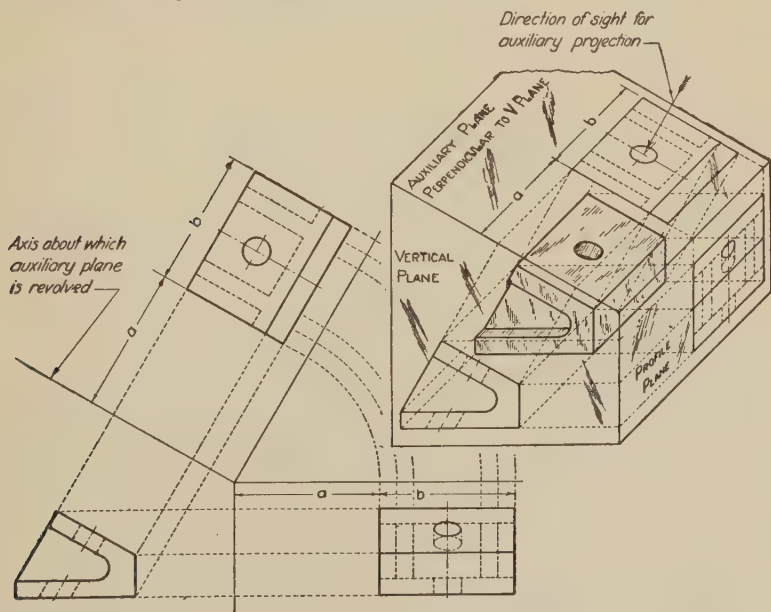


FIG. 1. Projection on one auxiliary plane.

**AUXILIARY PLANES AND VIEWS.** — The simple bevel washer shown in the pictorial drawing of Fig. 1 is an object of the type



mentioned in the preceding paragraph. The upper or inclined face of this object will not show in its true shape on any one of the three principal coordinate planes because it is not parallel to any one of them. Therefore, an auxiliary coordinate plane is set up parallel to this face and perpendicular to the V-plane as shown in

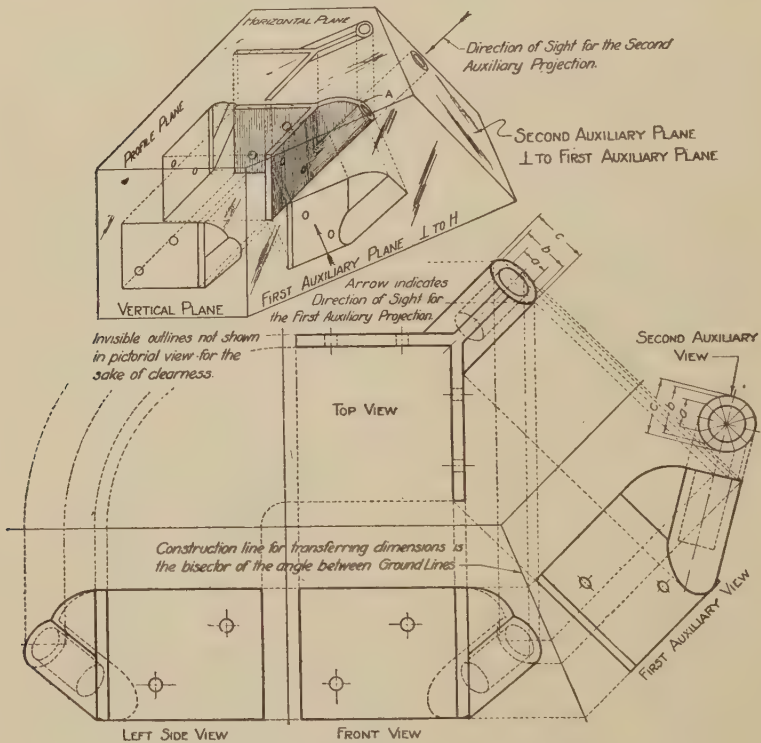


FIG. 2. Projection on two auxiliary planes.

the figure. After the auxiliary projection has been made in the usual manner, the auxiliary plane is rotated about its line of intersection with the V-plane away from the object, according to the rule of revolution established in the preceding chapter. The first drawing of Fig. 1 shows the relation of the projected views after the rotation of the planes is completed and indicates the method of projecting dimensions from one view to another. It will be noted that the projection of the circle in the end view cannot be constructed without the aid of the auxiliary projection.

The auxiliary plane which is finally set up to solve a problem

must fulfill two conditions: first, it must be parallel to the face of the object whose true shape it is desired to show, and second, it must be perpendicular to one of the planes of projection already in use. The plane used in Fig. 1 satisfies both of these conditions but it is not difficult to conceive of objects in which these requirements could not be met by a plane perpendicular to one of the three principal coördinate planes. Figure 2 represents just such an object and indicates a method of solution.

A plane placed parallel to the face *A* of the socket of the flag-staff support in Fig. 2 would not be perpendicular to any one of the principal coördinate planes. If, however, an auxiliary plane is first set up parallel to the elements or axis of the socket and perpendicular to the H-plane, then the second auxiliary plane may be set up perpendicular to this plane and parallel to the face *A*, thus fulfilling the two essential requirements. In turning the auxiliary planes from their original position until they coincide with the V-plane, the same general procedure is followed as in Fig. 1. The planes are rotated away from the object and about their line of intersection with the plane to which they are perpendicular as an axis. The lower part of Fig. 2 shows the relations of the five views to each other after the rotation has been completed. The actual distances of the object from the planes of projection have not been maintained. It should be noted that these auxiliary planes are used, not merely as a means for showing the true shape of particular faces or portions to which they are parallel, but also for constructing the views on the principal coördinate planes. In the case of Fig. 2, neither the top, front nor left side view could be completed without both auxiliary views. By carefully tracing out the projecting lines from the auxiliary views to the top, front and left side views, the actual use made of the auxiliary projections in the construction can be seen. The dimensions *a*, *b* and *c* in the second auxiliary view are usually transferred to the top view by means of dividers. Only that face of the object that is parallel to the second auxiliary plane need be projected upon it as a general rule.

It occasionally happens that it is necessary to make a bottom view of an object. This situation may be handled with an auxiliary H-plane by placing it below the object and following the usual rules for projection and rotation. See Fig. 3.

The auxiliary V-plane of projection is likewise employed in making a rear view of an object. The same rules for projection and rotation

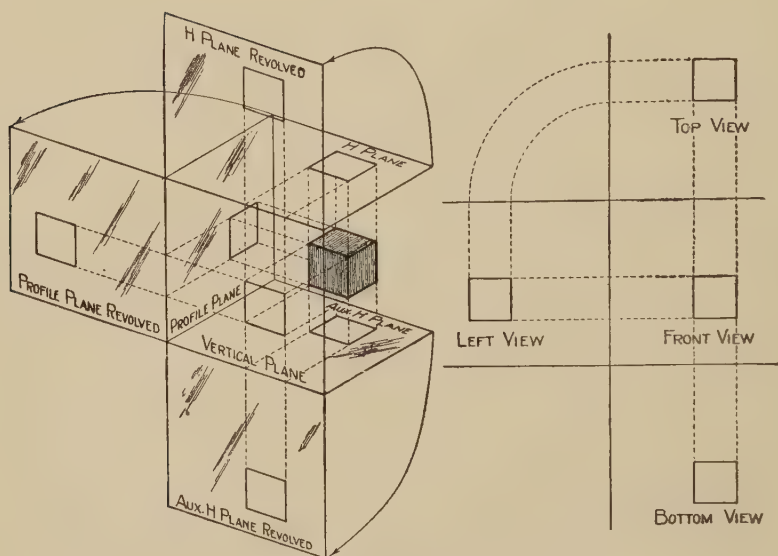


FIG. 3. Bottom view and auxiliary projection.

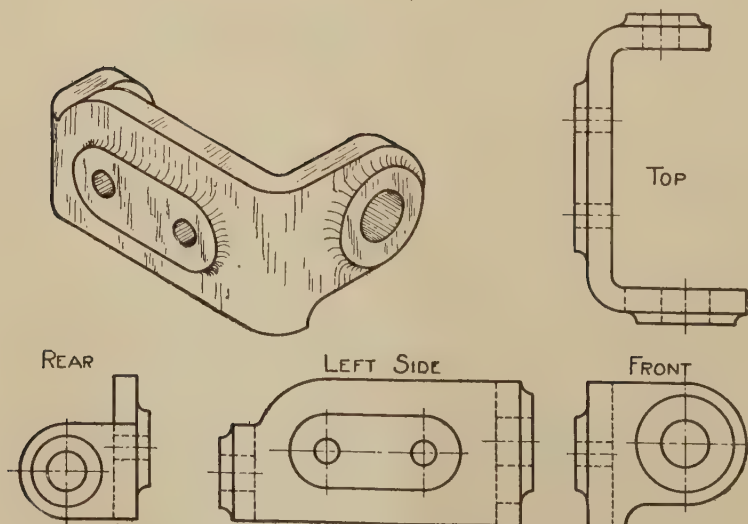


FIG. 4. Correct position of rear view

hold as before. A standard arrangement of views is shown in Fig. 4. When space on the drawing paper does not permit the standard arrangement to be followed, or for other reasons it seems advisable, the planes may be rotated so as to place the rear view above the top view.

As has been pointed out in the preceding chapter, the so-called ground lines, although shown in the illustrations, should be removed after the views of the object have been completed and before they are dimensioned as working drawings. It is possible, and also desirable, to construct these views without the aid of ground lines, by using some line or plane on the object itself as a reference line or plane, and then making measurements from it and transferring them from one view to another by means of dividers. The reference line or surface usually employed is the center line or plane. By this scheme the views may be placed closer together, but it should be remembered that the relation of the views to each other remains the same and that they must still be "in projection" with each other, whether ground lines are used or not. A working drawing having auxiliary views made without the use of ground lines is shown in Fig. 14, Section 1, of Chapter VII.

**SECTION PLANES AND VIEWS.** — If no further principles of drawing were available, it would often happen that the views obtained upon the planes of projection thus far discussed would be obscure and almost impossible of interpretation because of the excessive number of dash lines on the drawings, resulting from invisible outlines which delineate interior construction. Furthermore, two and three view drawings sometimes fail to show the real shape of an object because of the absence of sharp contours on the object itself and a consequent lack of definitive lines in the drawing. This condition generally obtains on castings of beds of machinery, hoods and casings for revolving parts, and other body structure where the stream line effect is sought in design.

One method of obviating this difficulty is to pass a plane or set of section planes, so-called, in such a way as to cut from the object certain portions which obstruct the view of the interior. One main cutting plane is always passed parallel to a principal plane, and the others, if there be any, are passed either parallel or perpendicular to the first cutting plane. The part of the object included in the angle of these cutting planes is considered as being taken away bodily, although, of course, the whole process is one

of the imagination only. The object is then projected in the usual way upon the principal plane to which the one main cutting plane is parallel, with the obstructing part removed. It must be clearly understood that this cutting away of certain parts of an object does not affect the drawing of any other view than the one on the

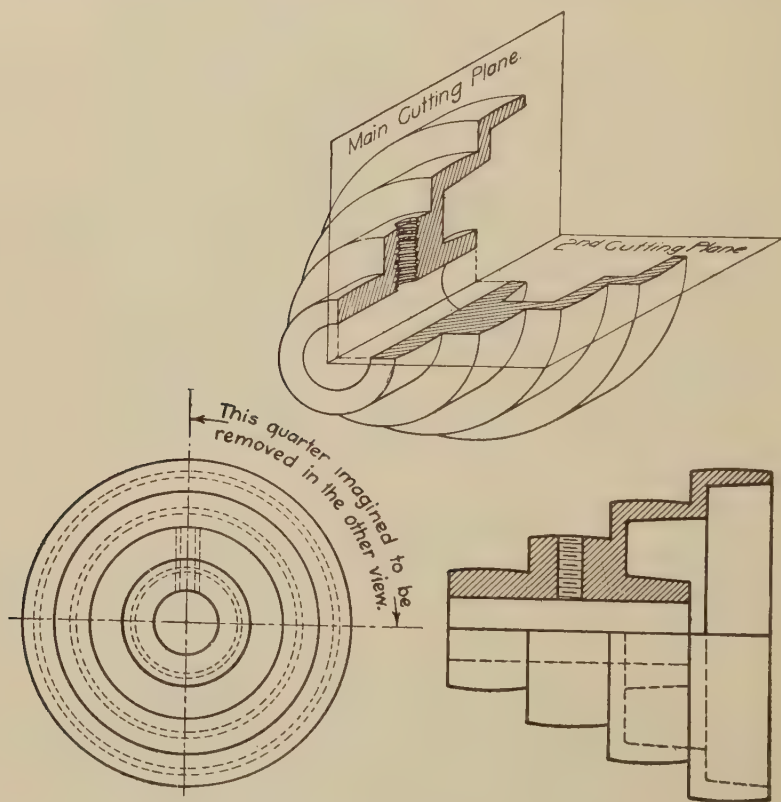


FIG. 5. Method of passing section planes

principal plane to which the main cutting plane is parallel. These other views are drawn just as if no section was being cut away at all. Figure 5 illustrates the general plan of passing the section planes and of representing the result in one of the main views.

The cutting planes are almost always passed through axes of symmetry of the object. It may occur that there are several such axes of symmetry not coinciding with a single center axis of the object, in which case the cutting plane is offset as in Fig. 6 to in-



clude both axes and thus serve a double purpose. No particular difficulty is experienced in reading the drawing when this is done; yet it is always best to show the location of the cutting planes by a characteristic line and the direction in which the view is taken by arrows, as is done in Fig. 6.

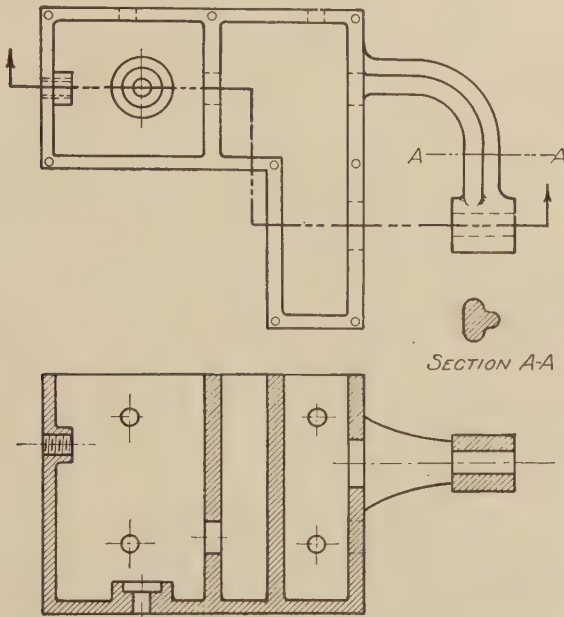


FIG. 6. Offset section planes.

It is the general practice to remove only one-quarter of an object by means of section planes, but often one-half is cut away. These practices have given rise to the terms "quarter section" and "half section" to describe the two procedures respectively. Much confusion has come about in drafting rooms and text books through the use of the words "half section" and "full section" to describe identically the same things as are described by the terms "quarter section" and "half section" respectively. This ambiguity arises from the fact that in the one instance — when the words "quarter" and "half" sections are used — the method of cutting the object is being described, while in the other case the result or appearance of the drawings is being referred to. The better practice is to use the phrases "half section" and "full section" exclusively, and no departure from this rule occurs in this text. Thus,

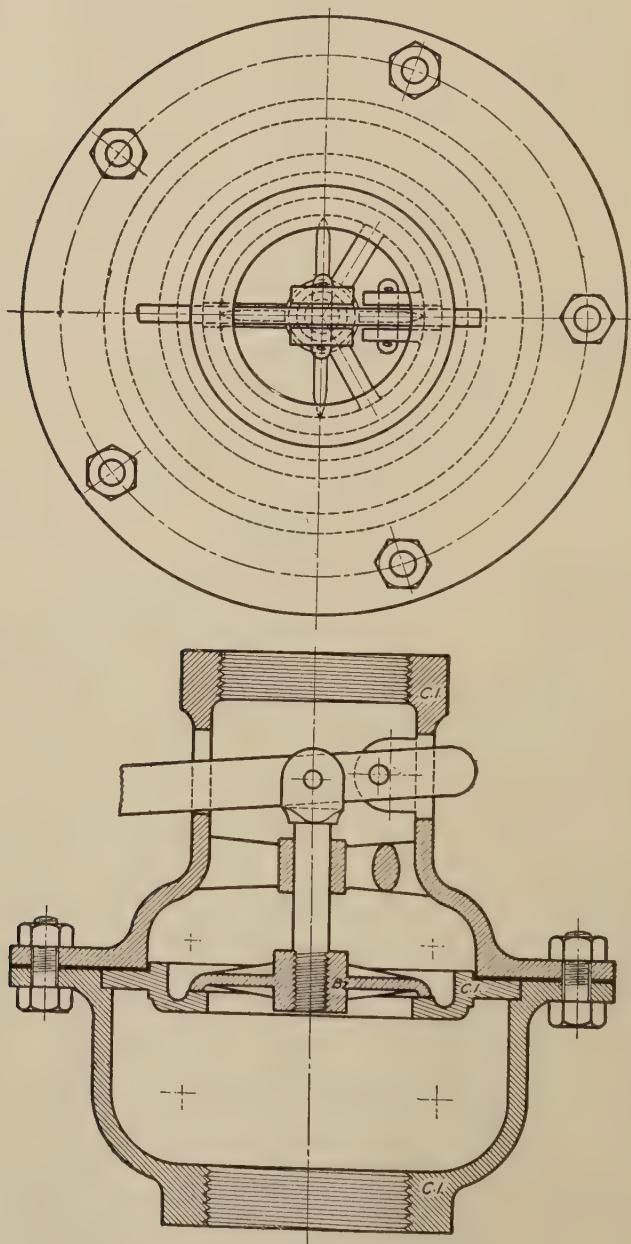


FIG. 7. Conventional sectioning.

we should speak of the front view in Fig. 5 as a half section, while the corresponding view in Fig. 7 would be called a full section.

When the cutting planes pass through the axes of solid cylinders, such as shafts, spokes of wheels, bolts and screws, it is the general custom to consider that these parts are not cut by the section planes, since nothing is gained by showing the interiors of such pieces, and a large amount of time is saved the draftsman on account of the omission of cross-section lines on the projections of such objects. Figure 7 illustrates a safety valve, several parts of which come under this rule.

It is also a standard practice not to show broken lines, representing invisible backgrounds of a section, across the section lines themselves. This rule may be violated in extreme cases where the drawing would otherwise be impossible of interpretation, but in most cases it would be better to draw another view or section.

**SECTION LINING.** — In order that those parts of an object which have been cut by the main section plane may stand out on the drawing, a conventional scheme called cross-hatching, or section lining is employed. This consists simply in drawing light, inclined lines on those parts of the view of the object which indicate

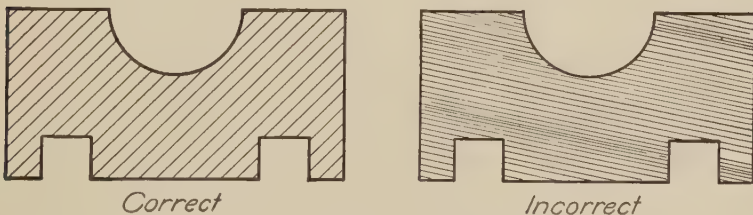


FIG. 8. Examples of section lining.

where the cutting plane actually comes in contact with the material out of which the object is made. The section lines may be drawn at any angle to the horizontal, but 45 degree lines are usually employed. They should be spaced uniformly and slightly less than one-sixteenth inch apart. In weight they should approximate a dimension line, and in all cases they should be drawn completely up to the outlines of the object. Figure 8 shows examples of good and faulty section lining.

Where several adjacent parts of a machine are of the same material and are cut by a section plane, each part should be distinguished from its neighbor by a change in slope of the section lining.

The more nearly the cross-section lines approximate 90 degrees to each other the better the effect will be. See Fig. 9. If the section plane cuts the same part at different places in the object,

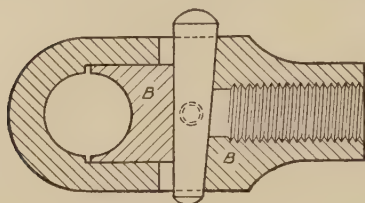


FIG. 9. Proper sectioning.

the section lining should, of course, be given the same slope in the two corresponding places on the drawing, as shown in Fig. 9.

Often adjacent parts of a machine are made of different materials, such as cast iron for frames with brass linings for bearings and seats. Here, not only should the section lining be changed in slope, but abbreviations, which will denote the kind of metal or material to be used, should always be inserted in open places made for the purpose in the section lining, unless this information is given in the form of notes placed outside the views. Formerly the commercial practice was to change the character of the lines themselves, thus requiring a new type of line for each kind of material. This practice has led to much confusion and waste of time, because of its elaborateness. Moreover, shop practice varies throughout the country, and complete charts have to be prepared and kept in each drafting room for the instant use of uninformed draftsmen. Only one thing seems to have been agreed upon by all draftsmen, and that is that full lines shall be used for white metals, such as steel and cast iron, while combinations of dot and full lines shall be used for the yellow metals, such as copper and brass. A typical chart of section lines for the various metals is to be found in the Appendix.

The authors of this text recommend the use of one kind of section line for all metals, with suitable abbreviations to denote each. Although in a few instances exceptions to this rule are proper, yet in the main its advantages are obvious and its application time-saving and easy. Figure 7 illustrates the practice recommended. A list of accepted abbreviations for the various metals is given in the Appendix. Attention is again called to the requirement that the same slope must be used for section lines on the different parts of a drawing which represent the same piece in a sectioned view. Note the application of the rule in Fig. 7.

For wood, stone, and other non-metallic materials used in construction, proper conventions and imitations should be used. A

chart of these well-nigh standard forms will be found in the chapter on Architectural Drawing, Part II.

**REVOLVED OR INTERPOLATED SECTIONS.** — In many instances the cross-section of some parts of a machine or structure may best be shown, without the trouble of drawing extra views, by passing a cutting plane perpendicular to one of the planes of projection and revolving the cross-section of the part concerned about an axis of symmetry within the cross-section itself until it is parallel to the principal plane. The revolved section is then projected upon the principal plane, to which it is parallel in the same way as is any other outline in the object.

Figure 10 illustrates the method as applied to cylinders, standard structural shapes, and hollow tubes. Figure 11 illustrates the

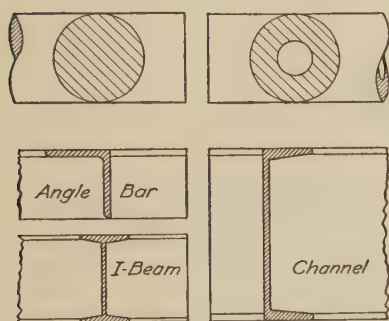


FIG. 10. Revolved sections.

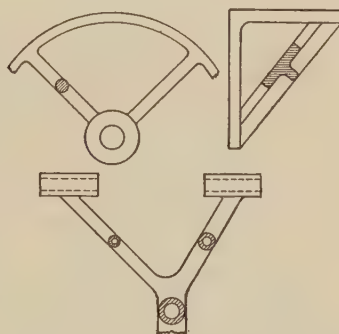


FIG. 11. Revolved sections.

same scheme applied to spokes of wheels, arms, and braces, in machines and other ribbed members. These revolved views are drawn with the same kind of section lines as are used on regular cross-sections explained above.

The advantages of these kinds of cross-sections are very great, inasmuch as they convey to the mind instantly the shapes of pieces used in the design of any structure, simply from an examination of one view of the object, without the necessity of a study of a second or third projection. Dimensions are frequently placed on such sections, thereby adding to their effectiveness. A slight variation in the method of placing the revolved section on the drawing is used by many draftsmen, namely, that of breaking out a portion of the piece being drawn at the point where the section is to be taken, and placing the revolved section in this break. Some advantages



are obtained in certain instances through the employment of this scheme. Figure 12 shows the arrangement of such views in a drawing.

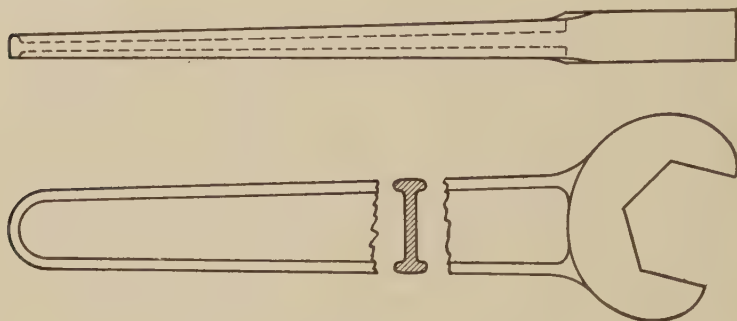


FIG. 12. Revolved section, broken view.

**REMOVED SECTIONAL VIEWS.** — In complicated machines and structures, it often occurs that neither of the methods of showing sectional views previously explained are suitable or sufficient, be-

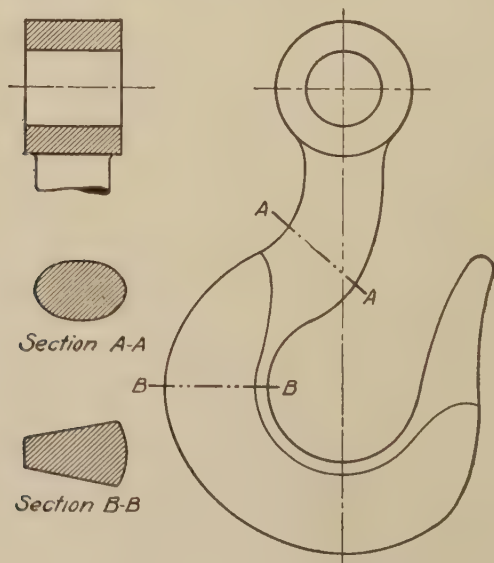


FIG. 13. Removed sectional views.

cause of the absolute necessity of showing the outside contours of the object with many full lines which must not be complicated by superimposed section lines. The method of overcoming this dif-

ficulty is simply to indicate on the principal views, by means of lines and arrows, where section planes have been passed, and then to remove the resulting cross-sectional views to some clear place on the drawing sheet. Figure 13 shows two such views taken at different places on the hook. Each section is "tied up" to the main views by means of such phrases as "Section AA," and "Section BB," etc. Proper notation to correspond to these sections is, of course, placed on the main views as indicated in the figure. Only the outlines actually formed from the parts cut by the plane are shown, except in a few instances where it may be proper to show some of the outlines behind the section taken.

One of the chief advantages of the above scheme of sectioning lies in the fact that the sectional views may be drawn to a much larger scale than the main views, thus showing the detail more clearly. A second advantage is that the main views showing the general outlines of the object are not confused by a large number of broken lines or cross-section lines. A third advantage may be found in the better balanced drawing sheets, since the cross-sectional views may be moved to any open space on the sheet.

**BROKEN SECTIONS.** — In some instances it will be found that a single interior detail needs to be made clearer than any of the principal views are able to make it, and yet the trouble of using any of the schemes of sectioning thus far described is too great to justify its use in the particular case involved. Resort may be had to still another method of sectioning illustrated in Fig. 14, and called a "broken section." The procedure is clearly presented by the figure.

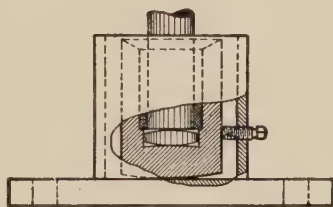


FIG. 14. Broken section.

## CHAPTER VII

### WORKING DRAWINGS

---

#### SECTION 1

Previous chapters have shown how the engineer or designer is able, through the skillful use of handy and accurate instruments, to convey to others ideas of the shape and form of his designs or inventions, by making drawings which are easily read because they embody certain well-understood principles or theories, called the principles of orthographic projection. Upon these principles all drawings for the builder's use are based; and no engineer can expect to have success in presenting his ideas and plans to others by means of the graphical language, unless he has acquired a complete understanding of the exact theory involved and has learned how to use his writing tools with facility and exactness.

However, it is very evident that the drawings which the student has learned to make thus far are mere skeletons, as it were, and cannot serve a very useful purpose until they are "dressed up" and made workable, just as outlines in written composition are clothed with detail and made workable. Various schemes for making the ordinary two or three view drawings absolutely clear, such as additional views on auxiliary and section planes, are helpful and necessary to the shopman who must construct the objects represented; but he must also be given information concerning the materials to be used, the nicety with which the parts are to be fitted together, the sizes required and many other data which will insure the production of just what the designer had in mind when he planned and executed his drawings. It is this feature of workableness or usefulness that has given rise to the term *working drawings*, or *shop drawings* as they are often called. It is the purpose of this chapter to acquaint the student with the methods he must employ to make his drawings really useful and at the same time pleasing to the eye, in short, to teach him how to make *working drawings*.

**WORKING DRAWINGS.** — Since Isometric, Oblique, and Perspective Drawings, to be explained in later chapters, are but seldom

used to build structures or machines from, it may be said that most working drawings are orthographic drawings. They must contain every bit of information that is necessary to make them completely workable and easily read. They must show the kind of materials to be used, and, through proper notes and conventions or symbols, they must indicate just how the several parts are to be made and fitted together. In addition to these requisites, working drawings must possess a style that is known to the craftsmen using them, just as a piece of well-written literature must possess a certain style.

Briefly then, we may say that *a working drawing of an object is an adequate number of correctly made orthographic views which have been accurately scaled and dimensioned and to which sufficient notes and explanatory statements have been added, so that the desired object can be made without further information.* Such drawings fall into two general classes, called *assembly* and *detail* drawings.

**ASSEMBLY DRAWINGS.** — As the name indicates, such drawings show the machine or structure as it will look when put together, with each piece or part in its correct working position relative to all the other parts. We cannot, therefore, have an assembly drawing of a single piece of a machine. Assembly drawings are made for very definite purposes; and, although they are only occasionally used in the shop in constructing the thing designed, yet on account of their general auxiliary use in making clearer the detail drawings, they are classed as working drawings. Unlike detail drawings of rather complicated things, they may be entirely useful with only one view shown. They may be made to serve one or more of the following important purposes, besides being used for actual construction purposes in limited instances.

1. As explanatory drawings to accompany complicated detail drawings. For this purpose the assembly drawing may be made on the same sheet with the detail drawings, or it may be made on a separate sheet to be bound with or attached to the detail drawings. By means of such assembly drawings, one may learn the exact function in the completed machine of each piece he is to make, and may consequently fashion his work with greater interest and effectiveness. One is able to learn immediately the accuracy required in fitting the several parts together, and the detail drawings are thus made more intelligible. See Fig. 1.

2. As the basis of preliminary studies of proposed designs and inventions. The movements of gears and cams, the relation of the

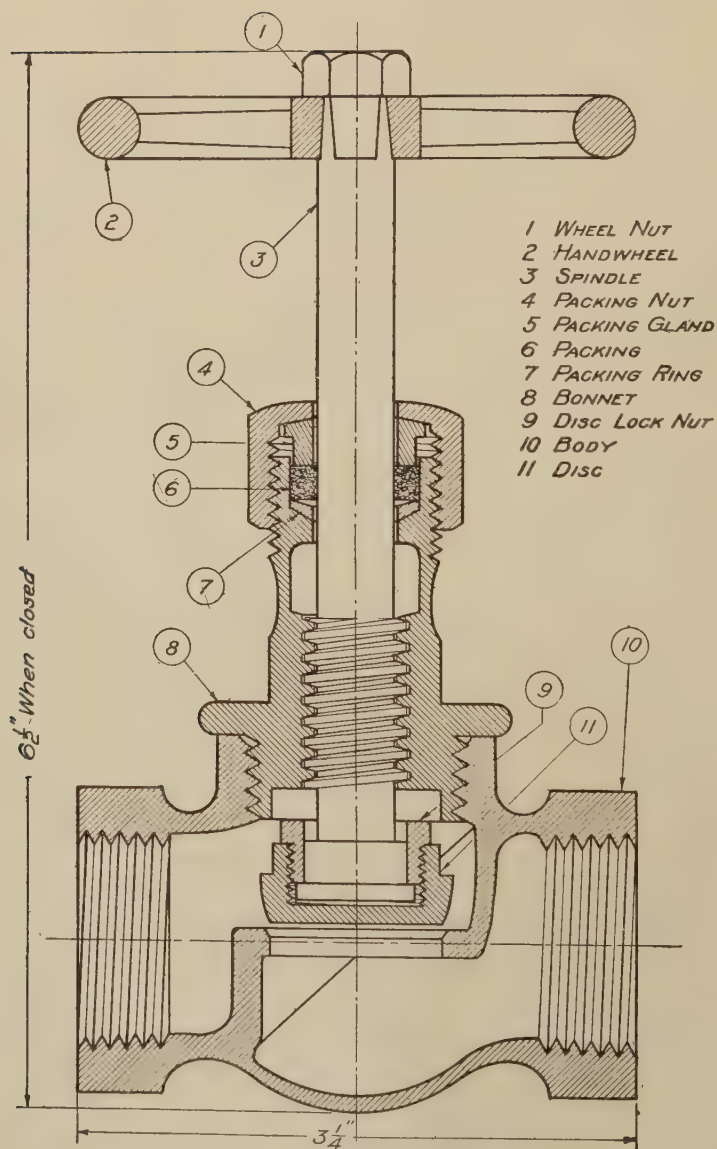


FIG. 1. Assembly drawing.



parts of a machine to each other, the general appearance of the finished structure and other questions affecting good design, are

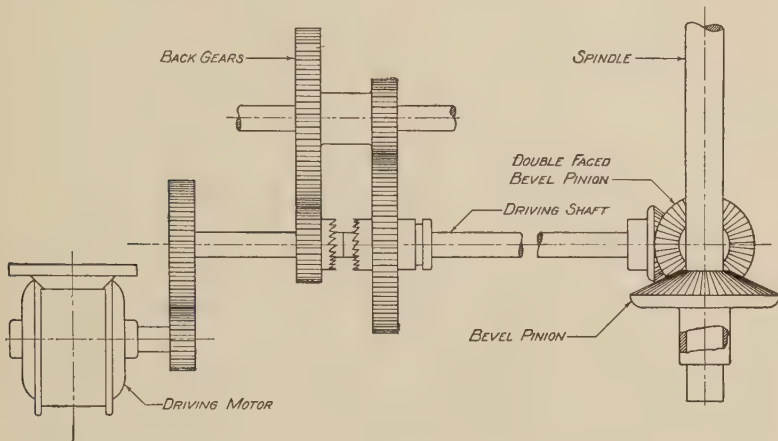
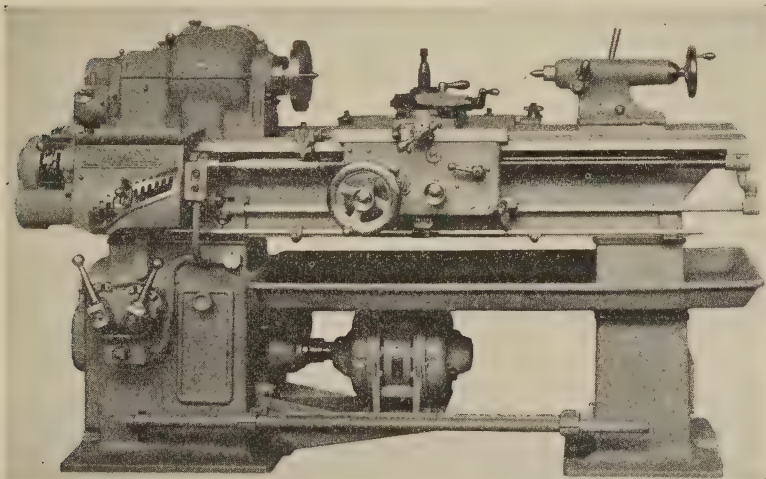


FIG. 2. Assembly drawing for design study.

often best determined from such drawings. Figure 2 is a good example of this kind of use of an assembly drawing.



(Courtesy Hendey Machine Company.)

FIG. 3. Assembly halftone for advertising purposes.

3. As indispensable guides in erecting and assembling machines of every kind. For such uses the drawing is often made more val-

uable by the addition of the name of each part, either by means of index numbers and a printed table or by means of leaders with the name of each part printed on the drawing itself. Figure 1 illustrates the first method.

4. As display or advertising drawings. In this case the drawing should be shaded where needed. Half-tone cuts from photographs of the actual machine or structure are rapidly taking the place of this type of assembly drawing. See Fig. 3.

Because of the definite and somewhat peculiar uses to which assembly drawings are put, there appear in all of them certain common characteristics which ought to be pointed out and emphasized:

1. Assembly drawings often consist of only one orthographic view. Circumstances dictate when more than one view shall be drawn. See Fig. 1.

2. Only overall dimensions are given, with the addition of certain center-to-center distances in important cases. See Fig. 1.

3. Section planes are freely passed, and hence a large amount of section-lining shows on each drawing. Figure 1 is a good example of the elaborate cross-sectioning to be found on many assembly drawings.

4. If drawn on the same sheet with the detail drawings, the assembly drawing should occupy the left side of the sheet, as a general rule.

**DETAIL DRAWINGS.** — When a working drawing of a single piece or part of a machine or structure is made, the drawing is called a detail drawing. As stated previously, such a drawing is composed of enough views to make the shape of the object perfectly definite. Dimensions and notes make clear the size, material, and shop processes to be carried out in its construction, so that an exact duplicate of what the designer had in mind when the drawing was made is assured.

For simple structures, the detail drawings of all the parts may be put on a single sheet. In this case the blueprints made from tracings of such drawings are passed from one shopman to another, in order that each may perform his part in making the whole, or the drawings are reproduced in sufficient numbers so that each workman may have a sheet of his own to work from. When the structure is more complicated, those pieces which are to be cast in the foundry, for instance, are put on one or more sheets, which are sent to the patternmaker; while pieces that are to be machined

from standard stock are put on other sheets and sent to the machine shop.

If each part is to be produced in large numbers, or if a number of workmen are to be assigned to a single job order, the draftsman is often required to put each piece on a separate sheet; this should be of a size to fit the circumstances, but often 9" by 12" is selected for convenience in binding and use in the shops. When all such drawings for a single machine or structure are brought together in one folio or binding, they are called a *set of details*. On the other hand, if several parts of a machine are shown on one sheet of paper, it is called a *sheet of details*. This latter type of drawing is often encountered in engineering practice; and the student should learn thoroughly both the fundamental elements entering into a well-made sheet of details and the order in which each should be considered in making the drawing.

The table below summarizes the factors which play an important part in making a sheet of details workable. These factors are arranged in the order in which they should usually be considered in the actual preparation of the drawing. The same principles apply in making sets of details.

#### Important Factors Entering into the Making of Working Drawings

1. Selection and preparation of paper.
2. Selection of title space.
3. Selection of scale.
4. Determination and arrangement of principal views.
5. Selection of sectional views.
6. Order of penciling.
7. Conventional lines and symbols.
8. Dimensioning.
9. Inking or tracing.
10. Bill of materials, notes and legends.
11. Checking and revising.
12. Reproduction in blueprints, white prints, brown prints, etc.

**SELECTION OF PAPER.** — This phase of the draftsman's work has been fully discussed in Chapter III under the caption Paper. It should be added that, outside of drafting rooms where standard sizes are already fixed for him, the draftsman should select his paper

with careful consideration of the uses to which the drawings are to be put, in order that the tracings and blueprints made from them, and sometimes the drawings themselves, may be filed conveniently without the added expense of special filing equipment or the necessity of objectionable folding.

**TITLE SPACE.** — Chapter II deals exhaustively with every angle of title making. However, it should be reiterated that the draftsman must take care to allow adequate space for his title before beginning any of his drawings proper. This should be done by laying out in pencil in the lower right-hand corner of the sheet, or other selected place, a rectangle of the size estimated to meet the requirements of the drawing. Sheets with the title form already printed on them make impossible any oversight in this respect.

**SELECTION OF SCALE.** — Two distinct ideas are connoted by the term *scale*, the first referring to the manner of subdividing the inch space on the rule itself, thus giving rise to the names Civil Engineer's Scale, Architect's Scale, and Mechanical Engineer's Scale, as explained in Chapter III, and the second idea referring to the *size* of the subdivisions rather than the *kind* of divisions. Strictly we should refer to the measuring stick itself as the *rule* and the divisions upon it as the *scales*. By common consent, however, the term *scale* is used to denote both the kind of instrument and the size of divisions marked upon it. Thus, we may speak, with equal propriety, of a boxwood scale and a scale of "half an inch equals a foot."

In selecting the correct scale for a proposed drawing, three chief considerations must be taken into account; (1) the kind of drawing being made, (2) the use to which the drawing is to be put, and (3) the size of paper available or fixed upon by the draftsman. Each is discussed below.

**Scales and Kinds of Drawings.** — In map work, the distances represented are so large that comparatively small scales are used. For convenience, the decimal system is used and the inch space divided into tenths, twentieths and other similar divisions up to one-hundredths. Such a scale is called a Civil Engineer's Scale, — often only Engineer's Scale, — and it is by professional sanction the only kind a draftsman may use on map work.

Measurements made on buildings, bridges, and the like are recorded in feet and inches; therefore, the scale used in laying off such dimensions must have the basic inch spaces on the ends of the scale divided into twelfths, to correspond to the number of inches



in a foot. Such a scale is called an Architect's Scale, and is the only scale used for the kinds of work enumerated above.

In shops and manufacturing plants, much of the measuring is done with a rule divided into quarter-inches, eighth-inches, sixteenth-inches, etc., so that the draftsman finds it convenient to use a scale on which the inch space is correspondingly subdivided into four, eight, sixteen and even thirty-two parts. This scale is called the Mechanical Engineer's Scale, and it is used extensively for strictly machine drawings.

It must be remembered, therefore, in selecting the scale, that custom has decreed the type of scale to be used for each class of drawings, and no departure from the established practice is allowable. Reference should be made to Chapter III for further mention of this phase of scale selecting.

**Scales and Uses of Drawings.** — In many cases, drawings are needed to show only the general outline of an object or plot of ground. A scale should be chosen, therefore, which will make an inch on the drawing equal to a large number of inches or feet on the object or ground. Such a drawing is called a *small-scale drawing*. Good examples are the standard United States Geological Survey maps, on which one inch equals 62,500 inches, and preliminary architectural sketches, on which one-eighth or one-quarter inch equals one foot.

Often, however, where details are sought, rather than generalities, drawings are made so that distances can be scaled accurately to as close as one thirty-second of an inch. For such purposes scales such as "three inches equals one foot," "one-half inch equals one inch," or even "one inch equals one-quarter inch," are chosen. Drawings made with such scales are called *large-scale drawings*. Almost any machine detail drawing is a good example of such scale selection.

It is clear from the two preceding paragraphs that the draftsman must know exactly the uses to which his drawings are to be put before he begins any work on them; and, although custom and standardization have already fixed his scales for him in many instances, yet in the main he will need to exercise careful judgment to secure satisfactory results.

**Scales and Sizes of Paper.** — Only a word of caution is necessary here in order that the engineer may not attempt too large scales, with a consequent crowding of the sheet when dimensions and notes are put on. Neither should he choose such a small scale



that only a part of the sheet is utilized and the drawings are made less useful thereby. Changes in size of scale or paper or both should be made, until a mean is struck which satisfies the dictates of balanced proportions between the size of paper and the drawings made upon it.

#### DETERMINATION AND ARRANGEMENT OF PRINCIPAL VIEWS.

— Before beginning any of the views on a sheet of details, a careful study of each piece to be drawn should be made, in order that the number of views and the planes on which they are to be drawn may be determined. Outline rectangles should then be drawn on

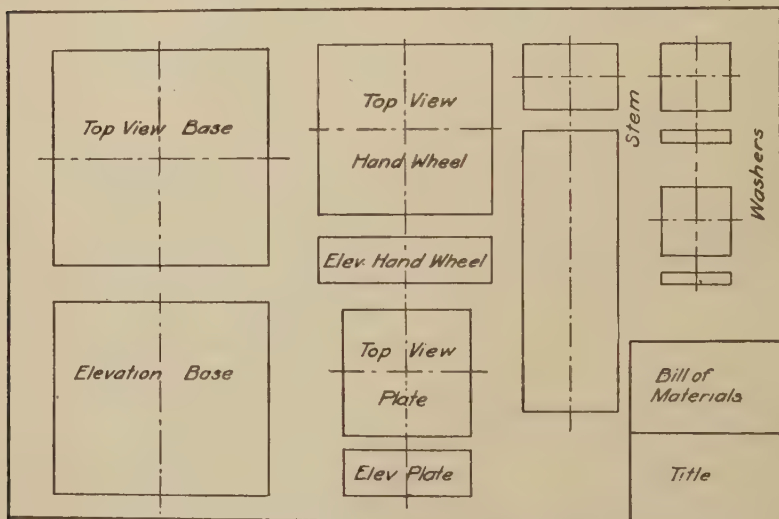


FIG. 4. Sheet layout for details of press.

the sheet, to scale, for each view, a proper space being left for dimensions and notes and reasonable distances between views and border lines. In some cases it may be advisable to cut from scratch paper squares and rectangles corresponding in dimensions to those of each view to be drawn, which can then be moved around at will on the drawing sheet until the best arrangement is found. Each view on the drawing sheet should be marked, in order that no error may occur in connecting the several views of a piece with each other so that they will project properly.

In fixing upon the arrangement of the different pieces or parts of an object on the drawing sheet, the draftsman should try to suggest

the relation of each part to all the others, as it is when they are assembled. The base or frame should be drawn in the lower left-hand corner and the other parts placed above and to the right of it, in such a way that, if one began at the extreme right and imagined himself assembling the object, each part would join naturally with its next left-hand neighbor and finally fit into the base itself. Nuts and washers, if drawn at all, should be drawn contiguous to the screws with which they belong; and bearings and pulleys should be arranged so that their position on a shaft or in frames and housings is suggested. Under no circumstances should the views of one piece be placed between the views of any other part. Figure 5 illustrates a good arrangement of the parts of the press shown in diagrammatic or layout form in Fig. 4.

Sometimes a better plan is to place the base in the center lower part of the sheet and arrange the details on both the left and right. This plan is feasible when a great many small details are found on each side of the center of the base, as would be the case in a lathe, for example. In any case much can be done, by systematic arrangement of views, to help those who must read the drawings to understand the relation of parts. Helter-skelter placing of details should not be allowed in any drafting-room.

**SELECTION OF SECTIONAL VIEWS.** —The planning of any necessary sectional views should be simultaneous with the determination of the primary views. Although removed sectional views may be placed in almost any location on the drawing sheet, yet it is always better to fix them in positions contiguous to the set of views of which they are auxiliaries; and in any instance the spaces they are to occupy must be marked off in the same way as are those for other views. Since sectional views may be drawn to give sizes as well as shapes, provision for dimensioning should be made in the space allotted to such views.

**ORDER OF PENCILING.** — After the different views have been determined upon and the final arrangement made, the draftsman should begin pencil work on all the views of one piece, and work back and forth between them with triangle and T-square.

Measurements common to two views of the same part should be laid off with the scale on one view and then projected to the other by means of the T-square and triangle, and not by use of the scale. Check measurements should be made now and then to ensure accuracy and avoid errors.

Only the most important and control dimensions should be put

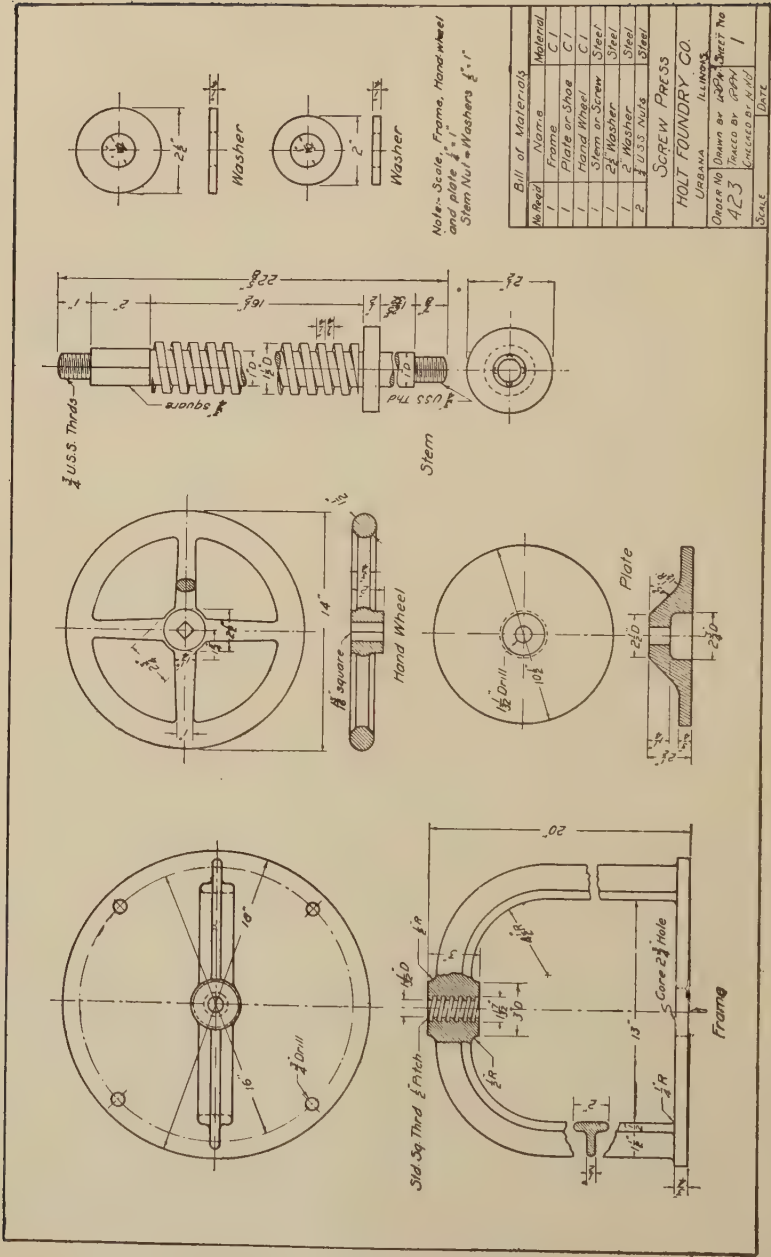


FIG. 5. Detail drawing of press.

on the views as the outlines are drawn; but after all the views are completed, each necessary dimension should be given and its location fixed in accordance with the Rules for Dimensioning listed below. In laying off distances, center lines should be utilized where possible. Dimensions should originate from center lines, however, only when corresponding measurements can be made in the shop. The draftsman should remember that distances to and between the centers of drilled or bored holes are a necessity in the shop, and his drawings, therefore, must show center lines for such holes, at least on the projection which shows them as circles.

If sectional views have been drawn, they should be cross-hatched and dimensioned before work is begun on the views of another part of the object. Each part of the machine or structure should be completed as outlined above, and the general notes and legends should be added to the drawing. Finally, bills of materials, if there are to be any, and the title should be lettered in.

A common fault with beginners is to slight the pencil work, since, as they say, "the drawings are to be inked or traced, and why waste time in making pencil drawings neat and accurate?" The answer is, that more time and money are lost by tracers trying to copy poorly done pencil drawings than it would have cost to have made the originals well. In all cases, the conventional lines, such as center lines, invisible lines, dimension lines and others, should be drawn accurately and neatly. Bad intersections of outlines should be prohibited, and every precaution taken to make the pencil work easily intelligible.

**CONVENTIONAL LINES AND SYMBOLS.** — It must be remembered that every line on a drawing should have a meaning which cannot be misinterpreted. In order that there may be as much contrast as possible among lines used for different purposes, custom and common consent have approved a number of conventional lines, chief among which are the center line, the dimension line, the invisible outline, and a few others. These must be adhered to strictly, and for convenience of reference the chart of these lines already given in Chapter IV is repeated in Fig. 6. The relative weight of these lines, as well as their form characteristics, should be noted carefully; and no intermixing or substituting of one for the other should be allowed when the pencil drawings are being made.

Again, it must be remembered that custom and efforts at stand-

ardization have decreed that certain symbols are to be used on drawings where the true appearance of an object is hard to reproduce or where many recurrences of the same things close together make it impossible to represent them at all. Many objects in every field of drafting have thus been symbolized, and comprehensive

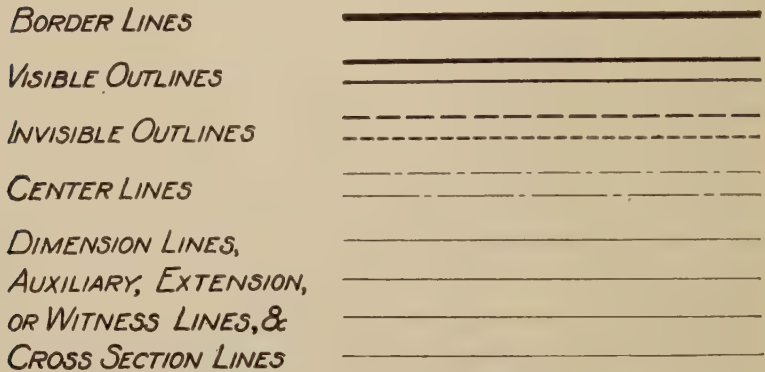


FIG. 6. Weight and character of conventional lines.

charts and tables of such symbols have been placed in the Appendix of this text. Continual reference to and use of them should be made by the student while doing his drawing work.

**DIMENSIONING.** — At no point in his work can the draftsman do more to injure the worth of his drawings, through ignorance of standards or careless and inaccurate work, than when dimensioning the various views. Not only must this part of his work conform to certain customs and standards, but it must be absolutely accurate. Parts of machines and structures must fit together when assembled, and since it is not uncommon for these parts to be made in widely scattered places and even in different countries, it will be seen that accuracy and clearness in dimensioning the drawings, from which the parts are to be made, are indispensable.

Three items of chief importance enter into the proper dimensioning of a drawing, namely: (1) the correct formation of the numerals and letters themselves; (2) strict adherence to approved standards both in the location and kind of dimensions to be used; and (3) a rigorous system of checking for errors of omission and commission alike. The first of these items has been treated in Chapter II under the caption of Lettering. The last item will be considered briefly under a later title. The second and most significant



item is given space below, commensurate with its value and importance to the draftsman. Let it be understood that in using the term "dimensioning a drawing" more than the actual placing of figures and letters on it is meant. All of the mechanical aids, such as leaders, dimension lines, explanatory notes, etc., are included in the phrase.

An inspection of Fig. 7 will serve to show that each line on the drawing is dimensioned by means of a simple scheme which is made up of three distinct parts: (a) witness or auxiliary lines extending out at right angles from the ends of the line being dimensioned; (b) dimension lines extending between the witness lines; and (c) the dimensions proper, consisting of the numerals and their attendant unit marks, such as feet, inches, and degree signs. In place of witness or extension lines and dimension lines, leaders, so-called, are often used, as is done in the case of the drilled holes in the figure.

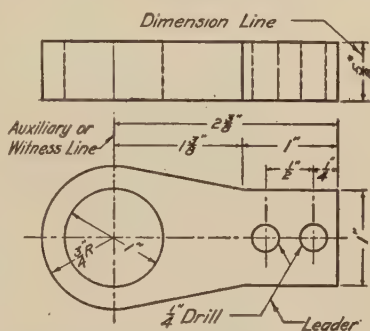


FIG. 7. Three elements of dimensioning.

The rules for correctly making and locating all these elements of dimensioning should be learned and understood thoroughly by the draftsman before he attempts to dimension his drawings at all. These rules are epitomized and illustrated in the Rules for Dimensioning Working Drawings given below.

### Rules for Dimensioning Working Drawings

1. Dimensions should read from left to right and from the bottom toward the top of the drawing sheet — diameters and radii of circles excepted. See Fig. 8. On auxiliary views, the dimensions must be so placed as to conform to this rule as nearly as possible.

2. Insofar as possible and practicable, dimensions should be placed outside of the views themselves, preferably between views — diameters and radii of circles excepted. See Fig. 8. The first line of dimensions should not be placed nearer to the outlines than one-quarter of an inch, nor farther away than five-eighths of an inch.

3. Witness lines should not be brought quite up to the outlines of the views themselves. See Fig. 8.

4. Open spaces should be left in dimension lines for the dimensions proper. See Fig. 8. In certain kinds of drafting, such as

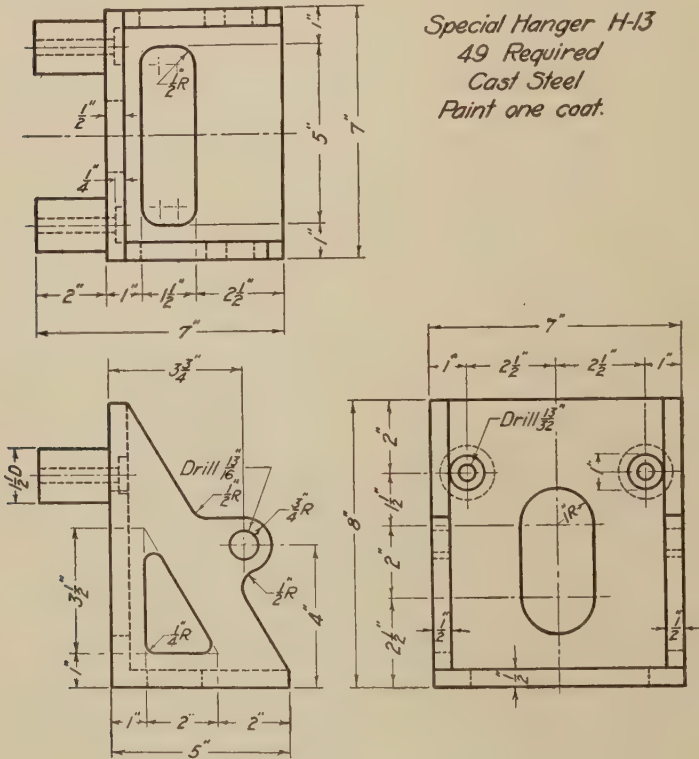


FIG. 8. Detail drawing of hanger.

occur in structural work, dimensions are placed along the dimension lines instead of in them.

5. Dimension lines, witness or auxiliary lines, and leaders should be light, full lines. See Fig. 8.

6. Arrow heads should be small, pointed, and fairly long. Their size should vary somewhat with the scale of the drawing and the spaces available for them. See Fig. 8.

7. Leaders should be made mechanically with two barbs on the arrow. The barbs themselves should be made freehand with a fine pen. See Fig. 9. One barb is sometimes used, but this prac-

tice is not enough of a time-saver to be recommended for general use. The use of arcs instead of straight lines is to be discouraged. Leaders made freehand are most effective if given an individual turn, as shown in Fig. 9.

8. Where center lines have been drawn in the various views, they should be used very freely to dimension from, provided, of course, that the shop man can also utilize the center line in the same way. Center lines used simply to indicate symmetry gen-

*Notes, legends and other lettering should be placed on a drawing horizontally.*

*Leaders should terminate horizontally.*

*Curved leaders may be used thus*

*Freehand leader used on architectural work.*

*One barbed leaders do not look well.*

*Two or more leaders close together should be parallel if possible.*

FIG. 9. Use of leaders.

erally fall in the category of exceptions to the rule. A drilled or bored hole should always be located by dimensioning to each of two center lines drawn at right angles through the point where the center punch for starting the hole will be set. See Fig. 8.

9. Dimension lines and dimensions proper should never be put along or on center lines.

10. Dimensions should not be repeated on two views. Overall dimensions may be excepted from this rule.

11. A series of dimensions should be kept in the same straight line and not offset. An overall dimension should accompany each series but need not be repeated on the same view. See Fig. 8.

12. Fractions should always have a horizontal line between numerator and denominator. This line should be in line with, but not a part of, the dimension line. Exceptions to this rule may be made where the space for the fraction is very small. An inclined line may then be used.

13. Where the space for the dimensions is too small for both numerals and arrow heads, several devices may be resorted to, such as placing the arrows on the dimension line produced but pointing in the reverse direction, omitting the arrows altogether, or using a

leader to carry the dimension to a more open space. See Figs. 10 and 11.

14. Insofar as possible, dimensions on outlines representing invisible portions of an object should be avoided. Other views or sections should be used. See Figs. 8 and 13.

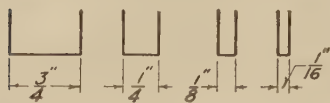
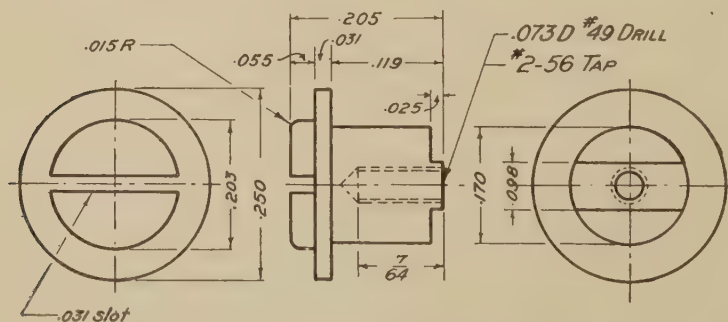


FIG. 10. Dimensioning in narrow spaces.

an open space both for the dimensions proper and the dimension line. See Fig. 13.

16. The diameter of a circle should, in general, be given on the projection showing it as a true circle. Where it must be put on the



NOTE: TOLERANCE ON ALL DIMENSIONS  $\pm .003$   
SCALE 1"=250"

FIG. 11. Decimal dimensioning.

straight line projection of the circle on account of crowded conditions on the other projection, the letter *D* should be used. The letter *R* should be used on radii of arcs. See Fig. 12.

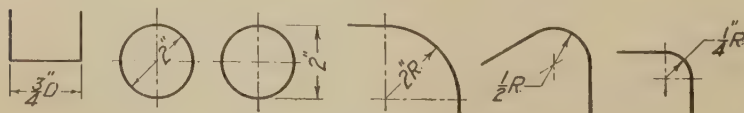


FIG. 12. Dimensioning arcs and circles.

17. Holes that are to be drilled, tapped, bored, reamed, counter-sunk, etc., should be so marked, as shown in Figs. 8, 11, 13 and 14.

18. Finished surfaces should be indicated by the small letter

"f" placed across the line representing the surface to be finished. See Fig. 14. If the object is to be finished all over, the note "Finish all over" is used and the "f" omitted. Such terms as ream, grind, spotface, and others have merit in indicating finishes, because they specify the exact machine process to be carried out.

19. In all cases the draftsman should remember that his dimensions are to show finished sizes. Allowances for shrinkage or for metal to be machined off a casting or forging are made by the shop man.

20. Dimensions on machine drawings up to twenty-four inches were formerly given in inches; over twenty-four inches, in feet and inches, e.g., 18" and 2'-11". Dimensions up to sixty and even seventy-two inches are now expressed in inches only, in many shops and drafting rooms. Dimensions on sheet metal work are usually given in inches only. Drawings of small framed objects, such as furniture and cabinets, are also commonly dimensioned in

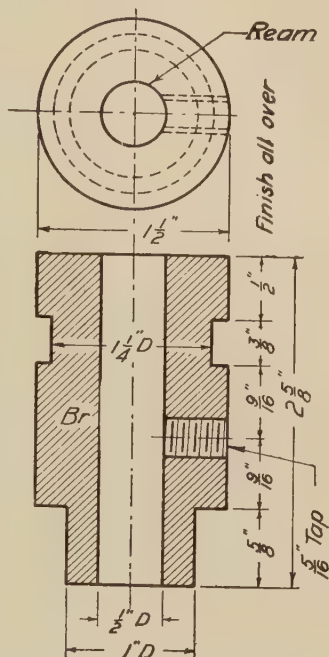


FIG. 13. Dimension notes.

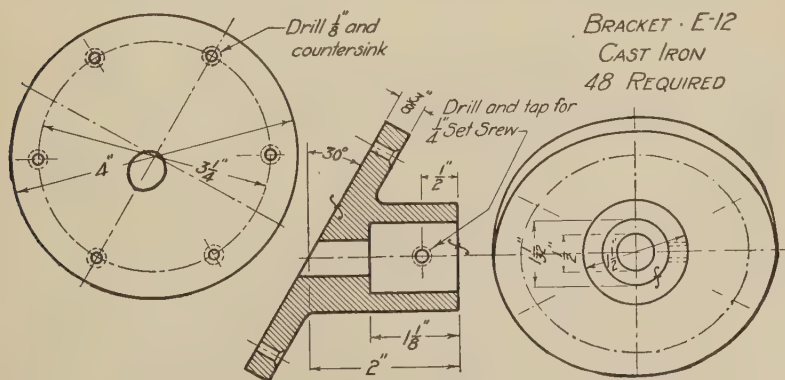


FIG. 14. Detail drawing of bracket.



inches. The general use of the five and six-foot machinist's and woodworker's rules encourage such practices.

**CHECKING AND REVISING.** — All well organized drafting offices have complete systems of checking a draftsman's work before it goes to the shop man. This is usually done, first, by the designing engineer or chief draftsman to see if points in the design conform to standard practice, and secondly, by an assigned draftsman or checker to see if various details of dimensioning and projection are accurate and clear. Revisions and corrections are indicated and

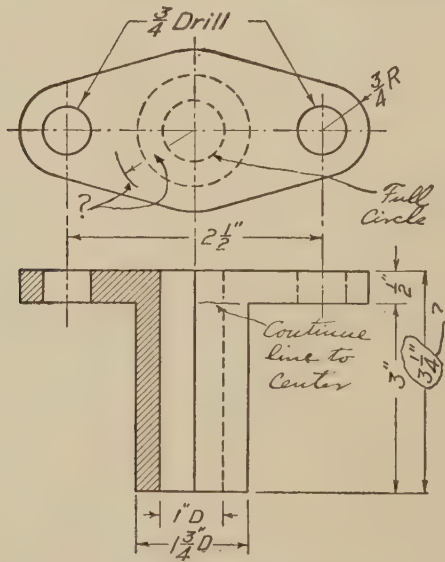


FIG. 15. Method of indicating revisions.

embodied in the drawings and tracings, and after final approval has been given by the engineer, they are turned over to the blue-printer for reproduction in quantity. Revisions should be indicated with a soft pencil, after some such method as is shown in Fig. 15. Each drafting office has its own standards for handling this part of its work, but the final results are the same. In checking a drawing, the following items should be given attention in the order named.

1. Check the drawings simply as orthographic projections, taking care that the shape of each part or piece is clear and fully projected in all views.

2. Scale enough of the projections to determine the accuracy of

the work and at the same time secure base lengths sufficient to make eye comparisons.

3. Check all dimensions by addition or subtraction.

4. See if shop processes are correctly indicated by notes and symbols.

5. Check for clearances of moving parts.

6. Check for clearances to insert, drive or tighten bolts, nuts or rivets with standard equipment.

7. Check all notes and legends and add to them where doubt arises as to the exact meaning intended.

8. See that the bill of materials contains all parts needed and that piece marks agree with those on the drawing.

9. Examine title to see that complete information is given, including scale, date, and names of engineers and draftsmen.

**INKING OR TRACING A DRAWING.** — After a drawing has been approved by the designing engineer or chief draftsman, it must be traced in ink on tracing cloth or paper in order that duplicates may be made by means of the blueprinting process or otherwise. In some cases where drawings such as patent office drawings, maps, display cards, etc., are being made, inking is done on the pencil drawing sheet itself. In each case several preliminary details should be carefully attended to.

If ink is to be applied to the sheet on which the pencil work is done, a quality of paper should have been chosen which will take ink readily. Soft, porous papers will not do, because of the tendency of the ink to run into the fibers. The paper should, of course, be white or some of the lighter tints. Before any ink at all is applied, the whole surface of the paper should be gone over with art gum and all dirt removed.

If tracing cloth is to be used, several precautions are necessary. The glossy side of the cloth should be placed next to the drawing to be traced, thus furnishing a slightly rough surface for the ink to adhere to. The cloth should be stretched tightly over the drawing and held firmly in place by numerous thumb tacks. The selvage edge should be removed and the drawing kept in a dry place while the work is proceeding. Powdered magnesia or other light prepared tracing powders should be applied to the cloth, to absorb grease and moisture, and then dusted off with a clean cloth or whisk broom. If the work is to continue over several days, the tracer should take care to confine each day's work to one portion of the sheet, in order that shrinkage or expansion of the cloth over

night may not affect the scale of the various views. The cloth must be kept free of lint and dust, and under no circumstance should water be allowed to get on the cloth, during the progress of the work or afterwards.

To prevent the ink from running under the tracing edge, a slight bevel may be provided on the underneath side, just sufficient to allow the ink to spread slightly without touching the straight edge.

In removing ink lines which have been drawn in error, care must be taken to leave the surface of the cloth fit for re-inking. For this reason, a knife or razor blade should never be used. All erasures should be made with the draftsman's "pencil" eraser, using the erasing shield to protect contiguous lines.

In order that tracing work may not be slowed up by wet ink lines all over a drawing, a fairly uniform order of doing the work should be followed. Not only will the work be speeded up, but the technique of the tracing itself will be enhanced by close adherence to the order suggested below.

#### **Order of Ink-work on a Tracing**

1. Center lines.
2. Ink in all circular or curved outlines.
3. Ink in all horizontal outlines, beginning at the top and working down the sheet, using the T-square.
4. Ink in all vertical outlines, beginning at the left side and working toward the right, using the triangle and T-square.
5. Ink in all inclined outlines, using raised straight edge if available.
6. Ink in dimension lines in same order as given above for outlines.
7. Letter notes, legends, and bill of materials, if made on the drawing proper.
8. Letter title.
9. Ink in border lines and trimming lines for blueprints.

**NOTES, LEGENDS, AND BILL OF MATERIALS.** — Any information needed to construct an object, which cannot be shown readily by means of dimensions and views, should be given on the drawing in the form of notes, with leaders to connect them to the proper parts of the drawing where necessary. Examples of such a method of conveying information on a drawing are to be found in: (a) instructions regarding some shop process to be carried out on a number of parts, (b) statement of kinds and sizes of bolts or screws to



be used, (c) directions concerning painting, enameling, hardening, etc. Many other similar bits of information are best given in the form of notes.

**Legends.** — When notes become rather formal in tone and take on the form of some standard or set phraseology, they are called legends or sub-titles. Common examples in make-up are given in the following arrangements placed near sets of views on a sheet of details: **Brass Bearing; 2 Wanted; or Half Elevation, West End.**

**Bill of Materials.** — Sometimes on the sheet of details, but more often on separate sheets prepared for the purpose, there is made up a list of all the pieces and parts needed to build the machine or structure. This list or table will contain the names of the several pieces, the materials of which they are made, the sizes of each piece insofar as these can be given in such a list, and the sheet and erection numbers. If the bill of materials is placed on machine drawings, it should become a part of the title. In the case of structural and architectural drawings, separate sheets  $8\frac{1}{2}'' \times 11''$  should be used. Figures 5 and 16 illustrate the method of making the bill of material on a machine drawing a part of the title.

**BLUEPRINTS, BROWNPRINTS, AND OTHER PRINTS.** — It is evident, of course, that the purpose of the tracing is to furnish an intermediate means of transferring the drawings to more useful form for shop and field purposes. The tracing itself must be preserved with great care, as it will become valueless upon being crinkled, moistened or stained. The blueprinting process, affording numerous reproductions of a tracing, allows us to utilize the tracing fully. So important is this phase of the draftsman's work that Chapter XV is devoted entirely to this subject, to which chapter reference should be made. It is necessary to point out here that good blueprints can be obtained only from good tracings, and to this end all tracings should be made with firm lines and proper conventional contrasts.

**PRACTICAL DRAFTING METHODS.** — The beginner must always bear in mind that drafting-room practice throughout the country is by no means standard for all shops. Many variations will be met with in actual work. Those principles and rules previously developed in this chapter constitute, however, the great body of drafting-room custom which forms the foundation upon which all shop drawings are made. Numerous problems will arise in actual practice which have not been mentioned heretofore. The solution of many of these will be found in Section 2 of this chapter, or in the Appendix.



## CHAPTER VII

### WORKING DRAWINGS

#### SECTION 2

**ONE WAY DIMENSIONING.** — Some commercial drafting offices are coming to use the type of dimensioning illustrated in Fig. 1, in which all dimensions read from the bottom of the sheet. On simple drawings, this practice is an advantageous one, both to the draftsman and the shop man. On complicated drawings, the method may result in much confusion, because in cases where interior dimensioning is imperative, the witness or extension lines are bound to cross each other frequently, and the dimensions themselves may easily be placed in such a position that it is not evident at first glance to which witness lines they belong.

**SOLID LINE DIMENSIONING.** — Another form of dimensioning, always in vogue in structural work and now seen in machine drawing rooms, is that of making the dimension line proper a solid light line and placing the dimensions above and along the line. See drawings in chapter on Structural Drafting.

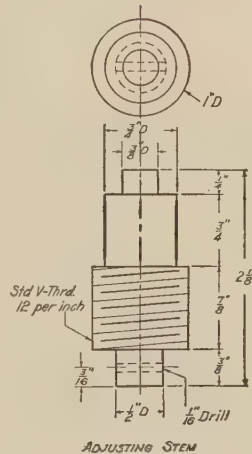


FIG. 1. One-way dimensioning.

**OMISSION OF FOOT AND INCH SIGNS.** — The French system of expressing all dimensions in millimeters, thereby permitting the draftsman to omit the unit sign (Mm), has a counterpart in many shops in this country, in the omission of the usual foot and inch marks ('), and the designation of the measurement simply by the total number of inches, it being understood, of course, that no other units are being employed. In shops where only small parts

are made, this practice has merit in that it saves time and is conducive to greater accuracy in calculating dimensions. Figure 2 illustrates this method.

Another scheme in dimensioning, very generally used in structural work and to a less extent in machine and architectural work,

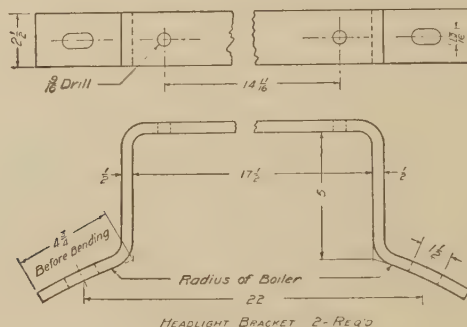


FIG. 2. Omission of inch marks.

is that of omitting both the foot and inch signs when both units occur in the same dimension, and retaining the inch marks for dimensions expressed in inches only; e.g., one foot and six inches would be expressed 1-6, while six inches would be written 6". In some drafting rooms the procedure is reversed.

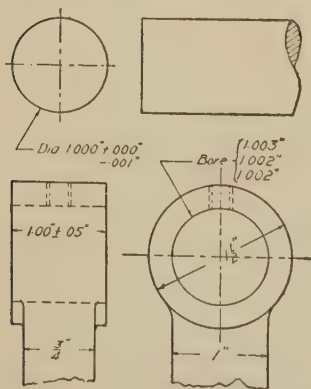


FIG. 3. Indicating allowances.

#### ALLOWANCES AND LIMITS.—

When dimensions are being put on drawings of pieces which must fit other pieces of a machine or structure to which they belong, within certain definite limits, it has been customary to indicate the degree of fit by the words running fit, push fit, driving fit, forced fit, and

shrinkage fit, without specifying on the drawing the allowances or limits permitted for each kind of fit. These allowance factors have been fairly well standardized, and most shops doing fine work now require these limits to be placed on the drawing in one of the ways shown in Fig. 3.

**METRIC SYSTEM.** — In drafting rooms where fine equipment is being designed for astronomical, physical, and chemical laboratories, metric units are regularly employed. The millimeter, of course, is the chief dimensioning unit. It is important that the engineer be able to think in terms of the metric system and to compare dimensions expressed in the one system with those expressed in the other. A table of metric equivalents is given in the Appendix.

**TRUE LENGTH OF OBLIQUE LINES.** — In ordinary drafting work, the lines representing edges or surfaces of an object lie parallel to some one of the principal planes of projection and, of course, project upon that plane in true length where a draftsman's scale may be used to measure them accurately. In some cases an

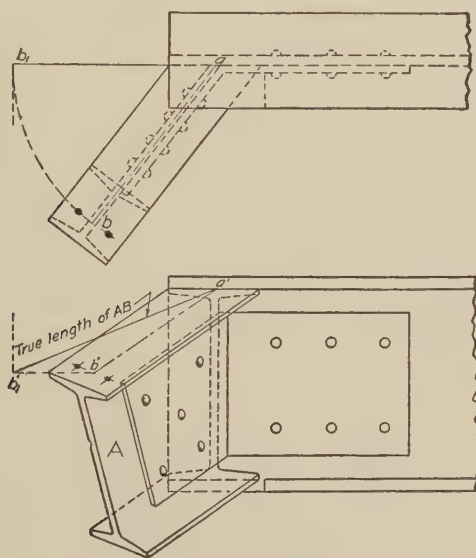


FIG. 4. True length of lines.

auxiliary plane is used, as explained previously, to show the true size or length of any outline oblique to the principal planes. There may arise, however, instances where the ends of an oblique line are definitely located and its projections determined thereby, and the length only is needed. In such a case, the draftsman should have recourse to the simple expedient of revolving the line parallel to one of the Principal Planes, which quickly gives the correct length

sought. An illustration of the application of this scheme is given in Fig. 4.

It is evident at once that no true dimensions of the beam marked *A* in the figure show in either of the two views. To obtain, let us say, the top center length from the end of the beam to the rivet holes, indicated by the projections *ab* and *a'b'*, revolve *ab* about *a* as a center into a horizontal position. Project *b'* horizontally until it comes to *b<sub>1</sub>'* just under the new position of *b*, called *b<sub>1</sub>*. Connect *b<sub>1</sub>'* to *a'*. The new projections show the line revolved parallel to the V-plane, and the projection *a' b<sub>1</sub>'* on the V-plane shows the true length of the top center line of the beam. This process is analogous to the turning of a wheel about a vertical axis until one of its spokes comes parallel to the vertical plane.

**INTERSECTION OF SURFACES.** — The draftsman is continually encountering the problem of how to represent the outlines of ob-

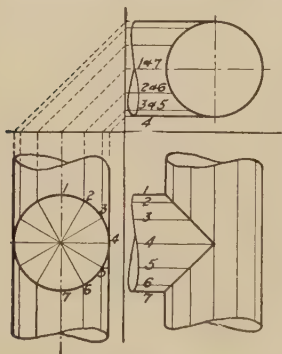


FIG. 5. Intersection of equal cylinders, axes right angles.

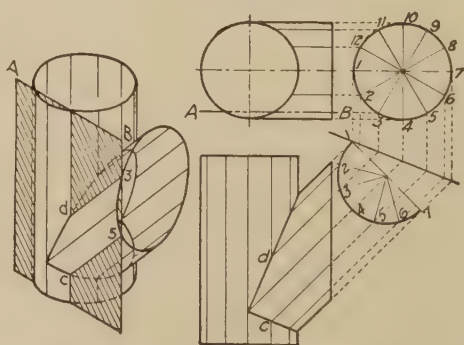


FIG. 6. Intersection of equal cylinders, axes oblique.

jects which have numerous intersections of geometrical surfaces, such as the cylinder, sphere, cone, torus, and other standard shapes. From the standpoint of all the theory involved, a discussion of these intersections belongs to the field of Descriptive Geometry. In practical work, however, many of the simpler problems may be solved by rules of thumb or some simple construction scheme.

Since an intersection of one object with another may be defined as the smooth line joining the piercing points of all the elements or elemental lines of the one surface in the other surface, a problem in intersections is usually best handled by first selecting and numbering the elements of one of the surfaces in some orderly fashion, taking care, of course, to choose a sufficient number to fairly cover

the whole surface, then finding in turn where each of the elements intersects the other surface. This procedure requires the use of both views of the drawing, and in some cases a third or auxiliary view is necessary. Figure 5 shows one method of numbering elements and finding where they pierce the second surface.

The finding of the piercing points of the several elements of the first surface in the second surface depends upon the fact that two lines in the same plane will intersect or be parallel; therefore, cutting planes are passed through the numbered elements of one surface in such a way as to cut elements or elemental curves out of the second surface. One such plane is shown in Fig. 6. The intersections of the elements thus cut from the surfaces by several parallel planes may be determined, and a smooth curve drawn through them. The student must remember that he is dealing with two views of the surfaces and therefore must show two views of the intersection. Figures 7, 8, and 9 show other simple inter-

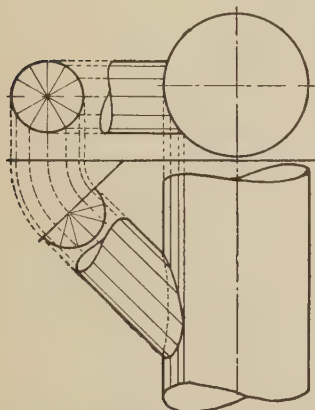


FIG. 7. Intersection of unequal cylinders, axes oblique.

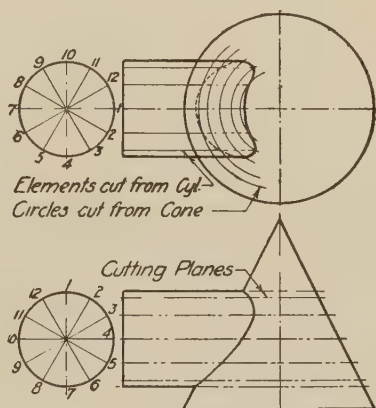


FIG. 8. Intersection of cylinder and cone, axes right angles.

sections. They are self-explanatory and will materially aid anyone taking the time to analyze them, to solve the usual intersections met with in drafting work.

In many intersection problems, it is impossible to determine where the various elements of the one surface pierce the second surface without recourse to more complicated theorems of Descriptive Geometry. Figure 10 illustrates one such problem. The solution is too involved to receive consideration in a text on drawing.



In some cases it is not necessary to determine intersections accurately, and the draftsman may sketch them in on his drawings by estimation only. Good examples of such cases occur on the intersections of the square and round parts of the shanks of carriage bolts, the intersections of square or hexagonal parts of the heads of bolts and screws with the rounded tops of the same, the inter-

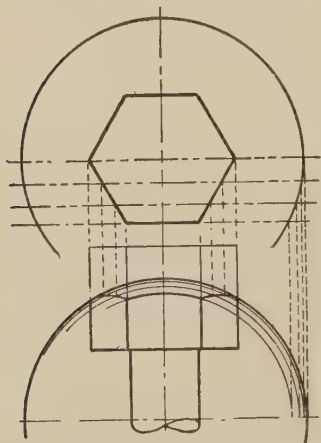


FIG. 9. Intersection of sphere and prism.

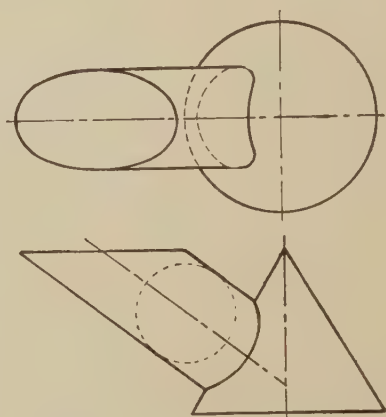


FIG. 10. Intersection of cylinder and cone, axes oblique.

section of the round shaft of a connecting-rod with its rectangular head, and many other cases where the curve of intersection is not to be developed or dimensioned. In none of these cases is it necessary to work out the actual intersections, since the experienced draftsman can always approximate them closely.

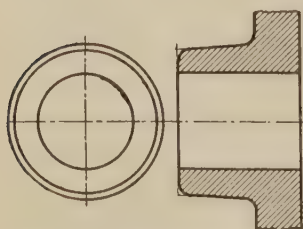


FIG. 11. Projection of fillet surfaces.

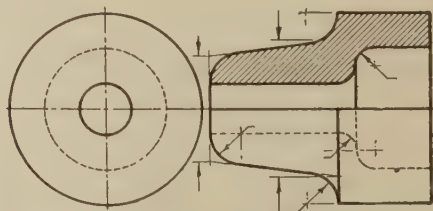


FIG. 12. Projection of sloping surfaces.

**FILLETS AND ROUNDED CORNERS.** — Closely allied to the question of how to represent intersecting surfaces is that of representing filleted and rounded corners in one of the principal views.

Figure 11 shows the sectional elevation of a tapering pulley hub with corners rounded or filleted. In drawing the end view, the question arises whether any circles, representing these parts of the hub, may properly be shown.

The rule should be followed in such cases that as long as the surfaces are at right angles to each other, or approximately so, and the corners are rounded simply to add finish, or the standard fillet is used to give added strength, then a circle should be included in the end view representing the circle of intersection before the corner was rounded or the fillet added. The dimension given should be that of the circle of intersection before rounding. The extended lines in Fig. 11 indicate the correct procedure to be followed.

If, however, the rounding of the corner is of large diameter and meets the other surfaces in tangential lines, and is done for the purpose of giving stream line effects to the design rather than simple shop corner finish, then the intersecting circles, if indeed there can be said to be any, should not be shown in the end view. Figure 12 furnishes an example of this kind. The dimensioning of the part involved should be carried out in the manner indicated in the figure. The center of the arc used should be located definitely if the curve is a circle and its curvature is an important factor in the design. If the curve is not a circle it should be specified by a system of dimensions based on a set of coördinate base lines. See Fig. 13.

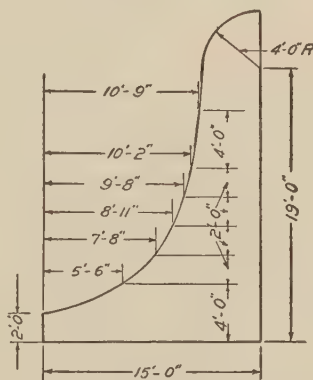


FIG. 13. Coördinate dimensioning.

**DEVELOPMENT OF SURFACES.** — With the development of the art of constructing so many everyday pieces of equipment such as containers, frames, and housings for machines by rolling or pressing sheets of metal into the desired form, has come the need for the engineer or draftsman to be fully cognizant of the methods used to lay out and cut sheet metal so that when rolled or pressed into form it will fit the designer's purposes as expressed in the working drawings. Exhaustive studies into these matters can be made only through the comprehensive use of the Descriptive Geometry. The simpler designs may be handled, however, through the use of ele-

mentary principles already studied in the chapter on Orthographic Projection. Examples of the development of a few plane and single-curved surfaces are explained below.

**Cylinders.** — The cylinder is a very common surface encountered in design. If its bases are parallel and perpendicular to the axis, it is easily seen that when split along any element and rolled out flat as in Fig. 14, a rectangle is formed. The length of this rectangle is equal to the length of the cylinder, and its width equal

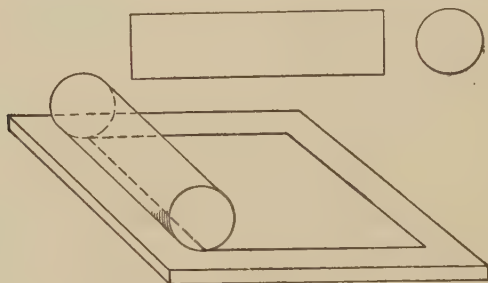


FIG. 14. Rolling out cylinder.

to the circumference of the cylinder. Both measurements are easily found from a working drawing.

When the bases are not parallel and neither is perpendicular to the axis, or when the cylinder is intersected by some other surface, such as a cone (see Fig. 10), the problem of layout or development is more involved. In such a case the length of the shape resulting from the development is found by taking the circumference of a right section of the cylinder and laying it out straight as a base line or stretch-out line from which to make other measurements. At suitable spaces along this base line corresponding to the true lengths of the arcs on the right section circle, distances to the left and right of it are laid off equal to the corresponding lengths of the elements to the left or right of the right section. A smooth curve joining the points thus located completes the development. Figure 15, which is a development of the cylinder shown in Fig. 10, will make this procedure clear for simple cases. Oblique cylinders cannot be handled this way and should not be attempted without further reference to the Descriptive Geometry.

Often a plane of symmetry may be passed through the axis of the cylinder, in which case the development is symmetrical about a line, provided, of course, that it is begun on one of the elements

in which the plane intersects the surface of the cylinder. In such a case only one half of the development need be shown. The cylinder in Fig. 15 could have been handled this way.

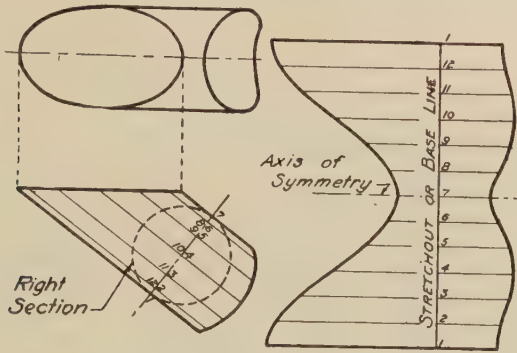


FIG. 15. Development of cylinder.

**Cones.**—Cones, when rolled out flat, develop into shapes which actually are or closely resemble sectors of circles. Figure 16 shows the simple right circular cone rolled out flat. It will be observed that the apex, length of element, and successive chord distances on

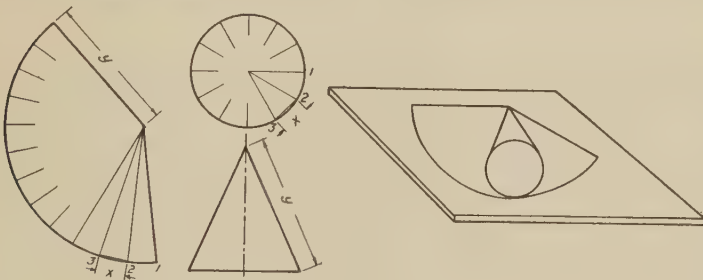


FIG. 16. Rolling out cone.

the base constitute the chief developing elements. If the cone is laid on a board along a split element, it will roll out flat with the apex remaining in one fixed position and the true length of the elements showing from this point to a circular curve. Successive elements will fall distances apart on the base curve approximately equal to the true chord distances on the base itself. We have, then, the joining together of several plane triangles, whose side lengths and bases are known (true lengths of the elements and successive chords) and whose vertices intersect at one fixed point, to form

the cone development. A smooth curved line is drawn through the base vertices, instead of a series of straight lines.

Figure 17 illustrates the procedure when the cone is intersected by some other surface. Figure 18 shows the method for an oblique cone.

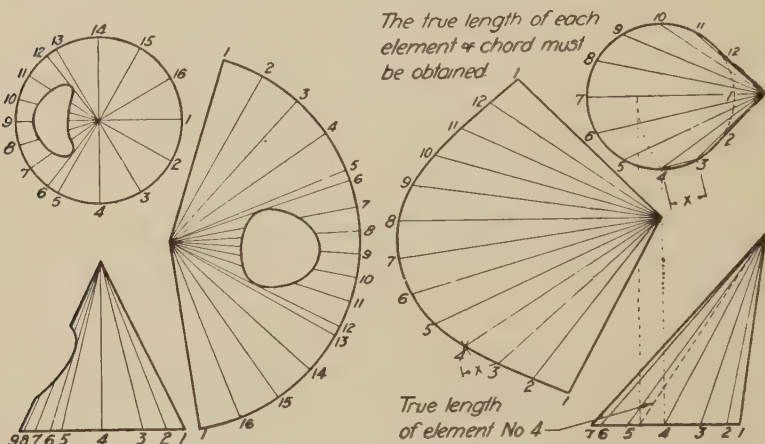


FIG. 17. Development of right circular cone.

FIG. 18. Development of oblique cone.

**Plane Surfaces.**—The surfaces of objects such as pyramids, prisms, and irregular-shaped plane-surface bodies, can be divided into triangles if they are not already in that common shape. Any triangle can be laid out on the drawing paper by simply finding the true lengths of all of its sides by the method already explained, and connecting these true length sides in the usual way for constructing a triangle. Each triangle in any one surface can then be joined readily to its neighbors, and the whole development completed. Each surface is turned into the development plane on the edge common to it and the preceding surface. Figure 19 shows the procedure applied to the pyramid.

If the object to be developed is a prism, and the drawing shows a right section, as in the case of the hexagonal prism of Fig. 20, it may be developed by the "rolling out" method, used with the cylinder, much more easily than by the triangulation method. The stretch-out line is the total length of the straight lines forming the periphery of the right section, and can be laid down as a straight line with the corner points determined. The location of the top



corner points are readily determined by laying off the true length of the elements on the proper line perpendicular to the stretch-out line. It is a good practice to number these lines on both the drawing and development. Straight lines join the corner points, instead of curved ones.

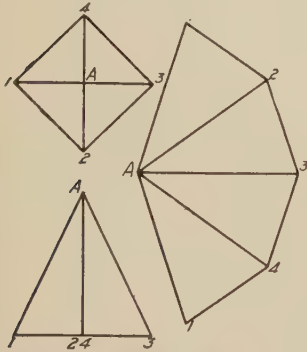


FIG. 19. Development of square pyramid.

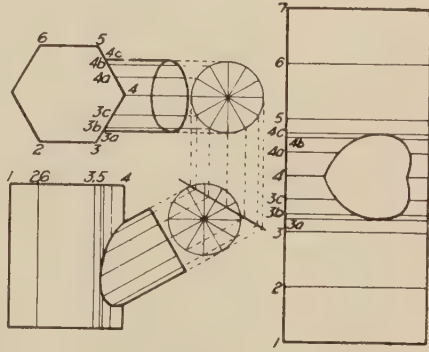


FIG. 20. Development of intersected prism.

**Outlines of Developments.** — The addition of a development to a drawing is for the purpose of furnishing the shop layout man with information and dimensions from which he can make a full size template of the shape to be cut from the sheet of metal, or from which he can lay out the shape direct upon the metal itself. It becomes important, therefore, that the template shall be as regular as possible in outline, first because of the cutting difficulties involved in very irregular outlines and, second, because of the economies effected in having the portion of the sheet or plate which is left after the desired piece is cut out, also regular in outline. It is readily seen from Fig. 15 that the outline of the development depends upon the element of the object at which the development is started. No definite rules can be given to control the choice of this starting element, since questions of how the joint is to be made after the metal is cut, whether seams may be allowed on alternate opposite sides, whether the joint is to be made in the shop or out on the actual job, and other points of similar character affect the decision materially. Judgment in these matters is attained only through experience on actual work.

**SHADE LINING.** — By the term *shade lining*, we mean making heavier, according to a conventional scheme, certain lines of a work-

ing drawing, to give it relief or the appearance of solidity. This process is seldom resorted to except for display drawings or patent office drawings, although formerly it was much in vogue.

This conventional scheme, briefly stated, is simply that the light is assumed to come from the upper left-hand corner of the drawing

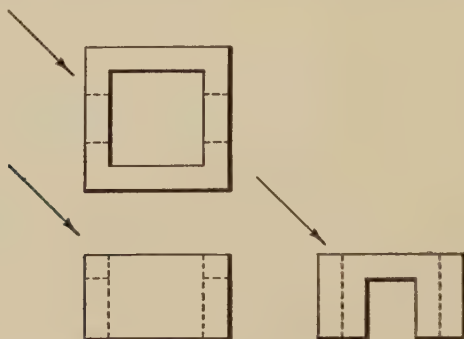


FIG. 21. Shade lining

paper for each view, as indicated by the arrows in Fig. 21. Lines which represent surfaces that are unilluminated are made heavier

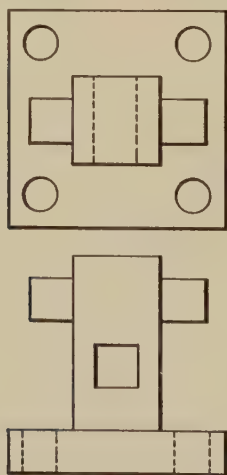


FIG. 22. Shade lining.

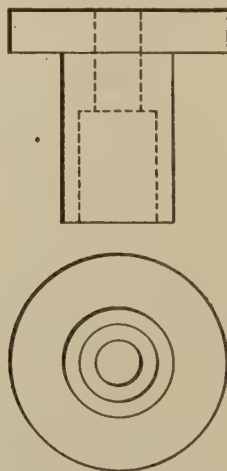


Fig. 23. Shade lining.

than the others. It will be noted from Fig. 22 that for solid bodies this makes the lower and right-hand lines heavier, while for openings in an object the left-hand and upper lines are heavier. Figure

23 shows the application of this principle to circular or cylindrical bodies. The extra thickness on circles is obtained by keeping the same radius but shifting the center along a forty-five degree line. The increase in thickness of lines should always be put on the inside of openings and on the outside of solid bodies.

**LINE SHADING.** — By the term *line shading* we mean the representation of differing degrees of illumination of surfaces of objects by means of ruled lines. By representing the rays of light as straight lines the theory of line shading may be worked out upon the principles of orthographic projection. The basic rules are briefly stated in the following paragraphs.

All objects are visible to us by the light which they reflect, and it may be stated as a general principle that the surfaces of an ob-

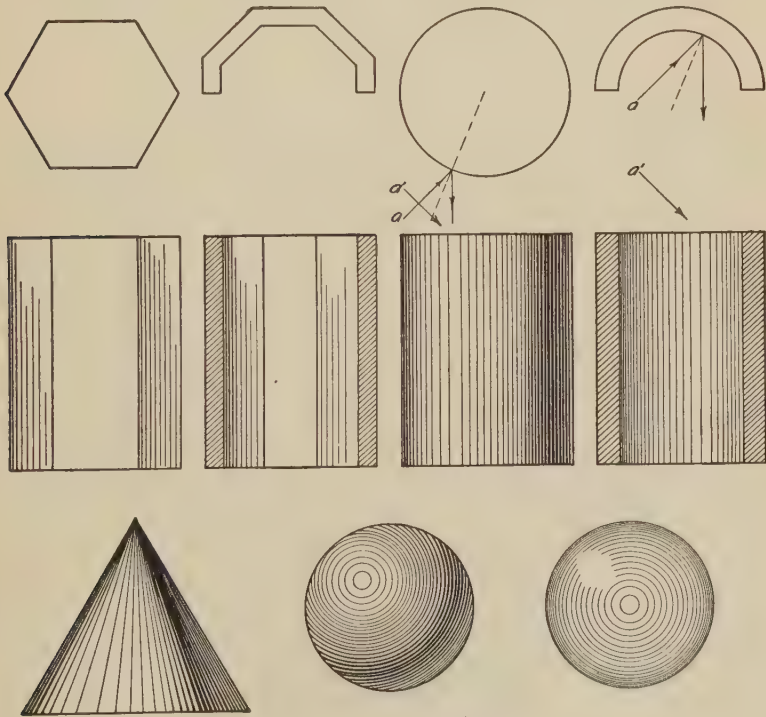


FIG. 24. Line shading.

ject are shaded in accordance with the amount of light which they reflect, the brightest area being made white and the darkest being represented by heavy rulings. The varying degrees of shade may be obtained in two ways, i. e., by drawing lines of uniform weight

and changing the spacing, or by changing both the spacing and the weight of lines. The latter method gives the most brilliant effects. The light is always assumed to come over the draftsman's left shoulder, as indicated by the arrows  $a'$  and  $a$  in Fig. 24.

For illuminated, flat, inclined surfaces, which presumably reflect light uniformly, the general principle is modified and the portion of the surface nearest the observer is made light, with a gradual increase in the density of the shading as the surface recedes. Likewise, for unilluminated, flat surfaces which would be uniformly dark, the rule is modified and the nearest portion is made dark with a very slight but gradual diminishing of the density of the shade as the surface recedes. Both of these rules are exemplified in the hexagonal prism in Fig. 24.

For cylindrical, conical, or spherical surfaces, the brightest portion of the surface is on the line or point of direct reflection. The location of this line on the cylinder is shown in Fig. 24. The shading is increased in density in both directions from this line. The darkest part of a curved surface is placed at the tangent point of the rays, although one would ordinarily suppose that the reflection from the parts beyond would be even less. Instead, however, the density of the shade is slightly reduced beyond the tangent point, as shown in Fig. 24.

Shade Lining is very effective upon two or three view working drawings, but adds little or nothing to isometric, oblique or other

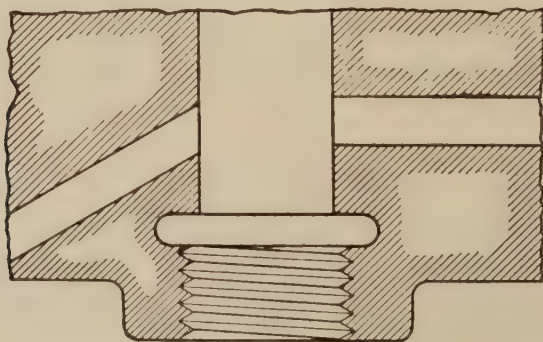


FIG. 25. Partial section lining.

pictorial drawings. It requires only drafting skill to execute well.

Line Shading, on the other hand, is most effectively used in one view drawings, such as isometric, oblique or orthographic assem-

blies. In addition to a thorough knowledge of the principles of orthographic projection, an artistic sense is required for its skillful use.

**PARTIAL SECTION LINING.** — In many instances, the appearance of large areas which have to be cross-hatched can be improved by simply drawing the lines only a short distance out from the edges of the surface and leaving the central portions blank, as shown in Fig. 25. Not only is time saved by this practice, but the otherwise objectionable black-ink areas are done away with. The blueprints of tracings made in this way are even more improved in their appearance.

**SECTIONING — ODD NUMBERED AXES OF SYMMETRY.** — In passing a section plane through such objects as pulleys with three, five, or some other odd number of spokes, or through webs of

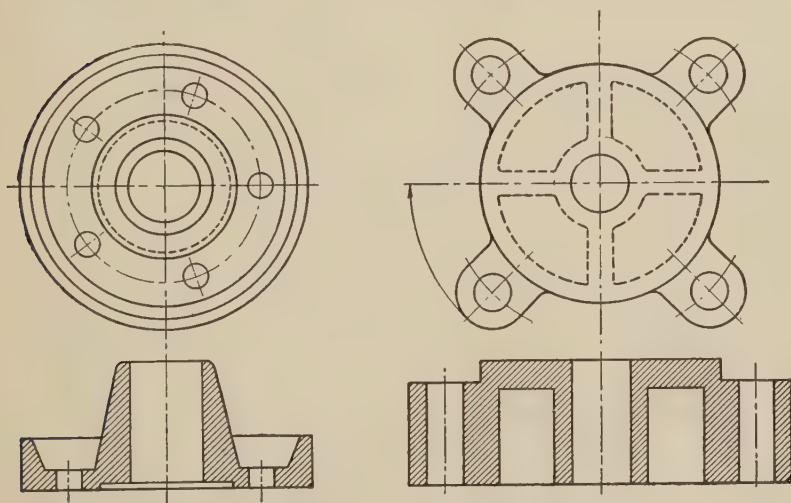


FIG. 26. Conventional variations in sectioning.

couplings with an odd number of drilled holes, and other similar objects, only one of the spokes or holes will fall in the plane. A second one will fall immediately behind the plane. It is customary to consider the latter rotated into the section plane when representing it, instead of showing it as it actually appears in true projection. See Fig. 26. Care must be taken not to extend this perversion of principle to objects which do not fall into the class of cylindrical shapes.



## CHAPTER VIII

### FASTENERS

In all kinds of structures with which the engineer has to deal, the various parts are held together in one complete whole by devices known as fasteners. These fasteners vary in kind and use, from ordinary nails and glue for wood structures, to nicely made bolts and machine screws for either large or small machines, such as locomotives or watches.

On working drawings, the engineer may specify certain fastenings by means of notes, without actually showing the fasteners proper on his drawings, or he may show certain of them in actual projected outlines or in some customary conventionalized form. Included among the former class of fastenings are such common things as spikes, nails, brads, cotterpins, dowelpins, and other simple devices. In the latter class are included such fasteners as bolts, rivets, keys, screws, pins of large size, clamp and lock devices, etc.

Little study of the fasteners listed in the first class is necessary from a purely drafting standpoint, and they are, therefore, omitted from further consideration in this text; but it must not be assumed from this omission that the engineer does not need to know when to use and how to specify them by proper notes and names on his drawings. Such knowledge comes, however, from practical experience in shop and field rather than from drafting room study. Fasteners in the second class need careful study from the standpoint of the drafting room methods and schemes of representing them, in addition to a knowledge of their use in field and shop. The remainder of this chapter is devoted to a study of the use, geometrical form, and proper representation of such fasteners on a drawing. Particular stress is laid upon those fasteners which have threads cut upon them and which are classified as either bolts or screws.

**BOLTS.** — A bolt may be defined simply as a rod of iron or other metal with a head on one end and threads on the other. The bolt can act as a fastener only when it has been inserted through holes

drilled in two or more parts, and a nut has been turned on the threaded end, thus drawing together tightly any pieces or parts between the head and nut.

The heads on bolts are pressed into the desired shape by heading machines after the end of the rod from which the bolt is made has been heated. Two common shapes predominate, namely, the square and the hexagonal. Correspondingly shaped nuts are used with each head; but on account of the better appearance of the hexagonal-shaped head and nut and also because such a nut can be used where full quarter turns of a wrench are impossible, it is the rule to find this bolt used on machine work, while the square head is used largely on rough wood and iron work. Figure 1 shows the two types of bolts described above, along with a group of other less common types. Attention is directed to three of the latter group, labeled Carriage, Stud, and Stove Bolts, respectively.

**Carriage Bolt.** — The oval head and square shank of the carriage bolt make it particularly useful for wood work where a high degree of finish is desired. Its head fits snugly down against the wood and the piece of square shank prevents the bolt from turning when the nut is being tightened.

**Stud Bolt.** — The stud bolt has no head and is turned into a threaded hole by means of a pipe wrench or special lock nut device. It is a very handy bolt because it can be used in places where it would be impossible to use a headed bolt, and it serves as an assembling guide for such parts as cylinder heads, manhole plates, and similar machine parts.

**Stove Bolt.** — The stove bolt is peculiar in that it has a round head which is beveled on the under side to fit a countersunk hole. It is provided with a screw-driver slot for turning the threaded end into the nut, rather than for holding the bolt so that the nut may be turned on to the threaded end. This bolt is used where it is

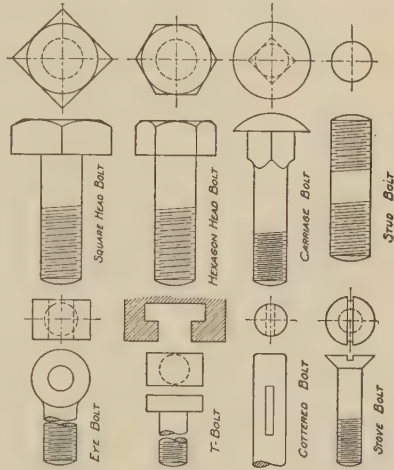


FIG. 1. Types of bolts.

desirable to have the head of the bolt flush with the surface of the metal held in place. The Tire Bolt is like the stove bolt with the exception that no screw-driver slot is provided. A second kind of stove bolt, not shown in the figure, is in common use; it differs from the other in that it has a round head.

The uses made of other bolts shown in Fig. 1 are indicated by their shapes and names. It should be added that on wood work a washer should always be used under the nut and often under the

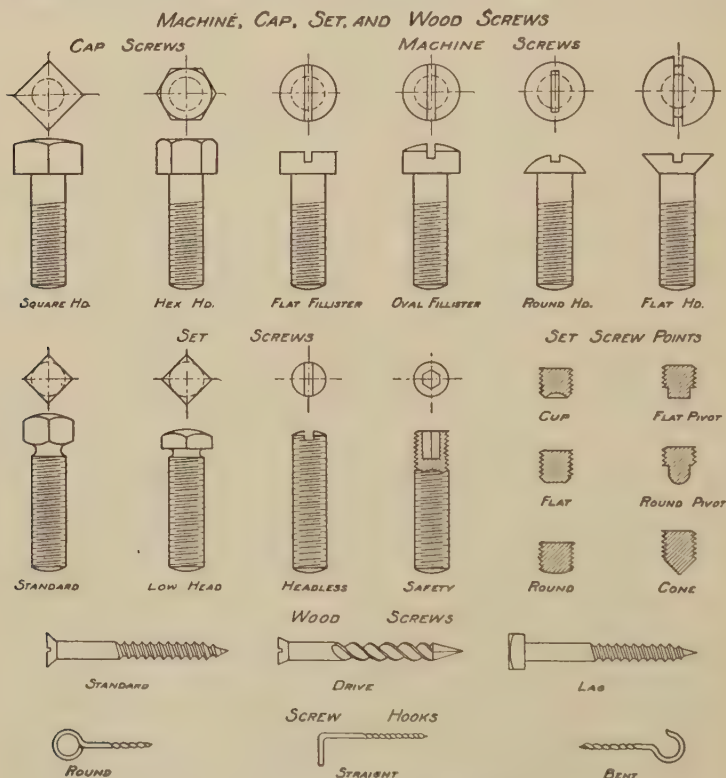


FIG. 2. Various types of screws.

head. In many places a washer should be used in machine work to prevent destruction of paint or finish.

**SCREWS.** — Figure 2 shows the common types of screws now in use. Comparison of this figure with Fig. 1 will serve to bring out the differences and similarities existing between the two groups of fasteners represented. Among the screws we recognize two types,

each intended for a particular use, namely, wood screws and machine screws. As in the case of bolts, we find the square and hexagonal heads and many other shapes to fit particular needs. In the case of wood screws, we find the heads provided with screw-driver slots, for turning, and the shanks threaded with comparatively coarse threads.

The chief point of difference between bolts and screws, however, lies in the fact that nuts are not used with screws because of the somewhat different method of employing them as fasteners. With bolts, as previously indicated, the pieces being fastened together are gripped between the head and nut, while in the case of screws one of the parts to be held acts as a fixed nut to which other parts are drawn under the head of the screw as it is turned. In the one case, heavy stresses occur in the nut; in the other, they occur in the head; hence the increased thickness in each case as compared with the head of the bolt. Set screws function, of course, through cup or friction grips of their points; hence, the pieces held are forced apart instead of being drawn together.

**THREADS.** — The important feature common to all bolts and screws is the thread. Nothing in the study of these two fasteners should be emphasized more, both from the point of view of the fundamental theory involved and more particularly on account of the method used in representing the thread, than the often underestimated features of thread form, as well as the thread conventions to be used in the drafting room. The basis for study of either is an understanding of the mathematical curve called the helix.

**The Helix.** — This curve, often miscalled a spiral, is generated in its simplest form by moving a point on the surface of a cylinder in a circumferential direction, at a constant angular speed, with a simultaneous uniform rate of advance in an axial direction. Figure 3 shows such a curve and the method of obtaining its projections. The linear distance the moving point travels parallel to the axis of the cylinder, in one revolution about the cylinder, is called the *pitch* of the helix.

We may have a point moving on the surface of a cone in accordance with the rules laid down above, in which case a conical helix is generated. Figure 3 also illustrates this curve.

There are several important things to be noted in the application of a helix of any kind to the study of thread forms. First, the surface of the V-shaped cuts in a threaded rod is simply a continuous series of helices of different diameters, laid close together from the

very tip to the bottom of the thread. This means that thread-cutting tools must be held in machines or devices which are designed to give simultaneously the two motions necessary to pro-

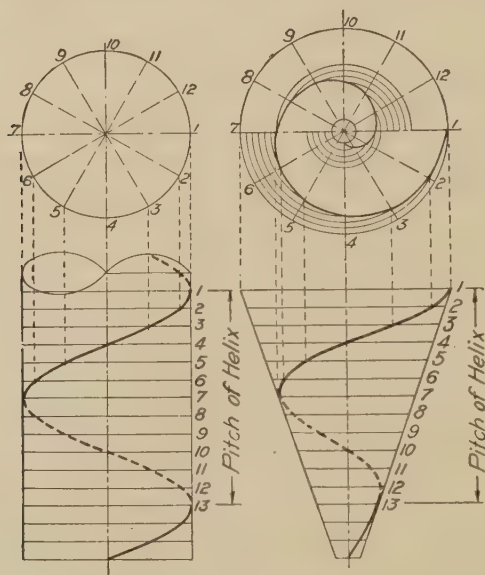


FIG. 3. Helices.

duce a helix. Second, the term pitch is transferred from its mathematical usage in connection with the helix to a commercial usage on threads, without change in meaning, except in cases where multiple threads, such as double or triple threads, are used.

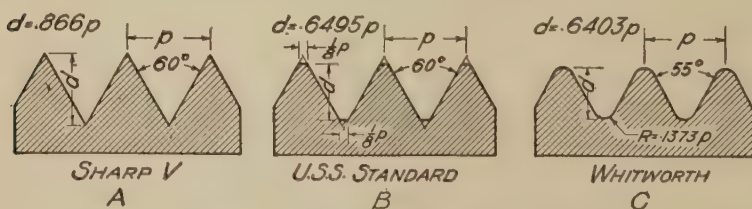


FIG. 4. Common thread profiles.

**Thread Forms.** — Figure 4, A, B, and C, shows common thread profiles. In A, the standard sharp V-thread (V) is shown; this is modified in B by flattening the tip of the thread and filling in the bottom an amount that will make the flats equal to one-eighth



the pitch, thus giving what is called the United States Standard (U.S.S.) or Sellers thread. *C* shows the British Standard or Whitworth thread (B.S.W.), which differs from the others in important respects. Obviously, the sharp V-thread is well-nigh impossible to manufacture, on account of its sharp points, and it has

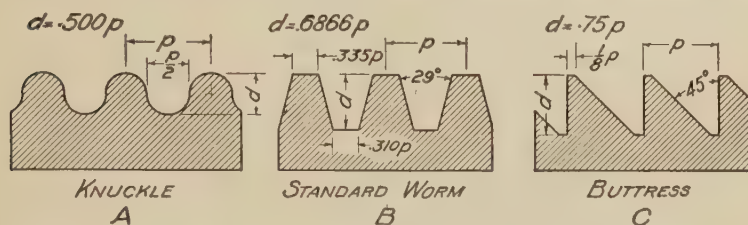


FIG. 5. Less common thread profiles.

been modified by a slight rounding of its tip and bottom, though not to such an extent as to make it comparable in shape with the U.S.S. thread. Other less common threads are shown in Fig. 5, *A*, *B*, and *C*. Each is designed to suit a special need, of which

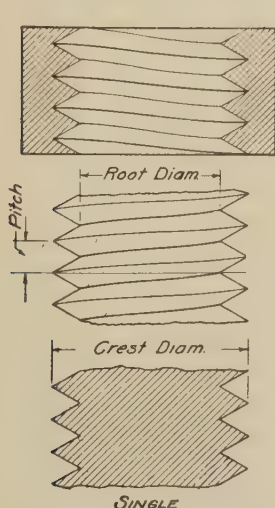


FIG. 6. Right hand threads.

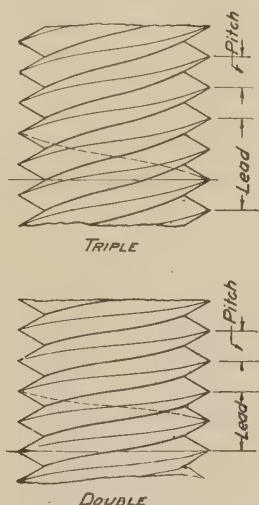


FIG. 7. Triple and double threads.

more may be learned by consulting any good Mechanical Engineers' Handbook.

**Thread Terms.** — The outside diameter of threads is known as the pitch or crest diameter, and is equal to the diameter of the bar on which the threads are cut. The diameter at the bottom of the threads is called the root diameter. The pitch of a thread is the

distance between the centers of adjacent crests measured parallel to the thread axis. See Figs. 4 and 5.

A thread is said to be cut right-handed when it will advance into a threaded hole if turned in a clockwise direction; it is cut left-handed if the reverse action occurs. Stated in another way, all right-hand threads, when viewed from directly in front with the axes vertical, show the crests of the threads on the side nearest the observer, sloping up from left to right. Figure 6 shows the slope of right-hand V-thread projections for various conditions encountered on drawings.

When two or more separate threads are cut on a rod, as shown in Fig. 7, they are spoken of as multiple threads, and may be double

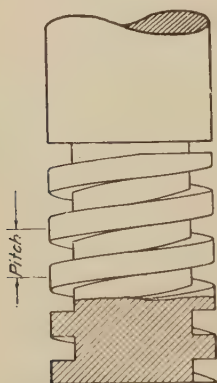


FIG. 8. Square threads.

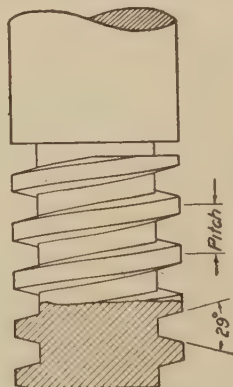


FIG. 9. Acme threads.

threads, triple threads, etc. Obviously, the thread curve is inclined more sharply to the axis than is the case of single threads, thus making the double or triple threads very useful where speed in an axial direction is wanted at the sacrifice of power-transmitting qualities. Common examples are found on tightening screws of lathes and on stems of quick-acting valves. The axial distance between the consecutive crests of the same thread is called the *lead* of the thread, while the pitch distance remains the same as in single threads, that is, the distance between the centers of two adjacent crests. The student should not forget this distinction when specifying threads of various kinds on his drawings.

It is often desired to move heavy loads or apply intense pressures to some object by means of machines and presses in which a screw transmits the power applied. In such cases a square thread is used, a profile of which is shown in Fig. 8. The thickness of the thread proper is always one-half the pitch. Since such threads are

used for special purposes, they have not been universally standardized except as to the tools to be used for various pitches; hence, they are always fully described by dimensions. They are cut on the lathe.

On account of the difficulty of cutting the square thread, it has been replaced to a very large extent by the Acme thread, so called. This thread is shown in Fig. 9. The angle of the thread is twenty-nine degrees; its depth is approximately one-half the pitch. In some respects the Acme thread is like the standard worm thread, although it differs from it in depth and width of flats.

In addition to the above standard threads, there are many others which have come into being through special needs of a particular branch of engineering. These standards have been set up usually through the efforts of the National Societies or Associations representing the particular branch of engineering in which the threads are demanded. Thus, we have the A.S.M.E. Machine Screw Threads; the S.A.E. Standard Thread; the International Thread; the Instrument Maker's Thread; and so on through the long list.

**CUTTING THREADS.** — Standard threads are cut with special automatic machines when bolts, nuts, and screws are being made for the trade. In the ordinary shop they are cut on the lathe or by hand. In the latter case, what are known as taps and dies are used, — the tap for cutting threads in nuts and drilled holes, the die for cutting threads on bolts, screws, and rods.

It should be noted that, in cutting threads with a tap, a hole must first be drilled with an ordinary twist drill, which when thus used is called a tap drill. For each size tap there is a corresponding tap drill. Tables in the Appendix show these relations of tap to tap drill. If fine, sharp thread crests are desired, the drilled hole should be reamed before tapping. It should be further noted that the diameter of the tap drill is a little larger than the root diameter of the tap, thus giving a thread of seven-tenths to nine-tenths the full depth of a perfect thread, which for ordinary use is sufficient. The crest diameter of the tap is, of course, a little larger than the diameter of the bolt or screw which will fit the threaded hole. None of these differences, called allowances, are shown on the engineer's drawings, as they are provided for in the manufacture of threading tools and machines.

**REPRESENTATION OF THREADS.** — Since the thread element is a helix, the thread surface is a warped surface; hence, it becomes a very tedious process to draw real outlines of threads on working drawings. Figure 6 shows the common V-threads projected as

they actually appear. The effect is pleasing, but the time consumed in drawing the curved lines is really wasted. Drafting room substitutes, called conventional threads, are always used to save time.

The first step in conventionalizing these thread forms was to replace the curved lines with straight lines. The second step was to omit the V-shaped profiles altogether, and to replace them with alternate light and heavy lines to contrast the crest and root lines. The final step was to disregard the exact number of threads per inch and simply space the representing lines about the same dis-

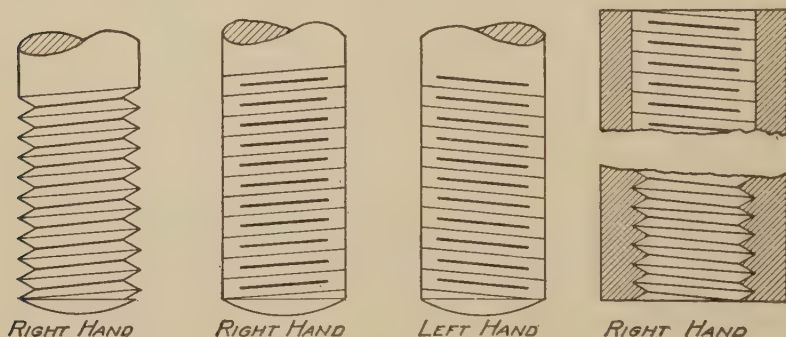


FIG. 10. Conventionalized thread forms.

tance apart and parallel, irrespective of the scale of the drawing, but keeping a relative ratio between small and large threads on the same drawing. The result of this simplification is shown in Fig. 10.

On ordinary scale drawings, the distance between two light or two heavy lines, representing the crest and root diameters respectively, is taken as about one-twelfth of an inch, which corresponds to a one-half inch bolt. By estimation only, this general average is varied sufficiently to show the different size threads on the same drawing. If the scale of the drawing is large, the actual V-profiles of the threads may be shown, and at the correct number per inch. The rise or slope of the thread lines should, of course, be one-half the distance between adjacent crest lines or about one twenty-fourth of an inch. Light guide lines should be drawn in pencil to terminate the ends of the heavy lines. After much practice one becomes proficient in estimating these values, and the skilled draftsman often omits actual measurements both in spacing and in obtaining the slope of the thread lines.

In some drafting rooms the conventions shown in Fig. 11 are used. The second method represented, in which both light and heavy lines are drawn horizontally, has some merit in that it saves time, but it is not as effective in appearance as the inclined-line convention.

Where threads are being shown behind other metal, it is good practice to further conventionalize their representation into the

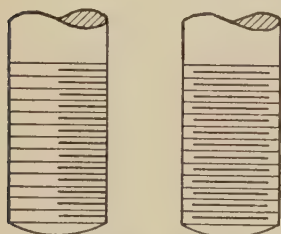


FIG. 11. Permissible thread conventions.

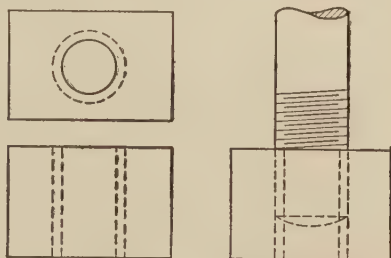


FIG. 12. Threaded hole conventions.

form shown in Fig. 12. This scheme should never be used when the thread outlines are visible.

In representing multiple threads by conventional methods, care should be taken to mark them as double, triple, or otherwise, since the slope of the lines is not always sufficient to completely identify this feature of the threads.

The methods of representing the square thread by conventional lines may be understood by a thorough study of Fig. 13.

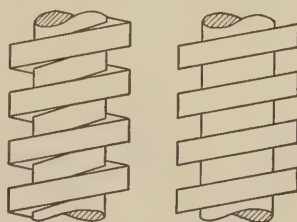


FIG. 13. Square thread conventions.

**REPRESENTATION OF BOLTS, NUTS, AND SCREWS.** — A bolt or screw, being simply a rod of metal threaded on one end and having a head pressed on the other, is easily represented on a drawing, as the threaded portion is shown in the conventional manner described in previous paragraphs, while the square or hexagonal head and nut are also represented by easily made outlines. Reference to Fig. 14 will call attention to the accepted use of circles for what in reality are hyperbolas in the elevation views of the head and nut, while the slope outlines on each are always at thirty or forty-five



degrees, depending upon whether the head is square or hexagonal. In the top view are shown the projections of the chamfer circle, the diameter of the bolt (dotted circle), and the square or hexagonal outlines of the head. The head or nut is always assumed to be turned into the positions shown, irrespective of how it may occur in actual work. The diameter of the chamfer circle is always the distance across flats. The radius of the circle representing the end of the bolt or screw is taken equal to the diameter of the threaded rod.

Practically all measurements on various parts of a bolt or screw are based on the diameter, which, of course, is always a known quantity. These measurements are derived from formulae which

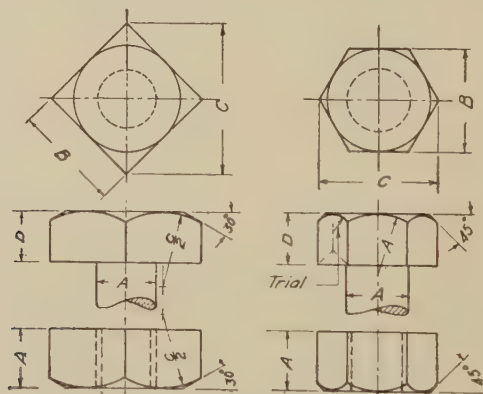


FIG. 14. Square and hexagonal bolt heads.

have been approved by long usage. Thus, for instance, if the diameter of the chamfer circle on the U.S.S. bolt is wanted for either the square or hexagonal head, it may be found from the standard formula,  $B = 1\frac{1}{2}d + \frac{1}{8}''$ , where  $d$  equals the diameter of the bolt and  $B$  the diameter of the chamfer circle. Likewise, the thickness of the nut is taken equal to  $d$  and the bolt head as  $\frac{1}{2}B$ . For the convenience of the draftsman and others, complete tables of sizes for all bolts and screws have been worked out, and reference to them may be made by consulting any Mechanical Engineers' Handbook. Some of the more commonly used tables have been inserted in the Appendix of this text.

Draftsmen often omit the top view of standard bolts and screws on their drawings, and where numbers of either or both occur on a single machine or object no drawing of them is attempted at all.

The threaded holes in the machine, however, are always shown by the proper convention.

The kind and extent of conventionalization which may be permitted on any bolt or screw of an odd character must be determined by the judgment of the draftsman, in conformity with the practices outlined for standard bolts and screws. A good handbook should be consulted concerning the numerous types not shown in any of the foregoing figures.

**DIMENSIONING BOLTS AND SCREWS.** — In completely specifying bolts and screws on a drawing, it is only necessary to give the diameter, length, kind of thread, shape of head, and the metal from which the bolt or screw is to be made. If the ordinary standard medium steel bolt or screw is to be used, no mention of the metal or the threads is necessary, as the common commercial standards will always be understood. These dimensions and descriptions are not placed on the drawing in the same way as are those for other parts of a machine, but are combined into a single note which is printed near the views of the bolt or screw; or if these views are omitted, they may be indicated in a note separate from any views whatever; in some cases the bill of materials will contain the only reference to the bolts and screws needed. Typical specifications are as follows:  $2\frac{1}{2}$ " Std. V-thread,  $\frac{1}{4}$ " pitch; 4" Acme, 4 threads per inch;  $\frac{1}{2}$ "  $\times$  2" U.S.S. Hex. Bolt;  $24\text{--}\frac{3}{8}$ "  $\times$  2" Sq. Hd. Mach. Screws;  $2\text{--}\frac{1}{2}$ "  $\times$  3" Lag Screws; 2 lbs. #3- $1\frac{1}{4}$ " Br. Wood Screws.

If the bolt or screw to be used is not standard, it must be drawn in two-view projection and the dimensions and descriptions placed upon it in the same way as is done for any other piece or part on the drawing. This requires the draftsman to know what is meant by standard sizes and how each dimension is measured on the bolt or screw.

**Important Dimensions.** — The length of a bolt, cap screw, or machine screw is always the distance from the tip to the under side of the head. In the case of headless bolts and screws, countersunk head bolts, and flat head wood screws, the length is the overall dimension. Standard bolts have threads cut on their shanks distances that vary from one and a half to five times the diameter depending upon both the length and diameter of the bolt. Extra long or large bolts are threaded for a length equal to three times their diameters.

**LOCK NUTS.** — A discussion of bolts and nuts cannot be considered complete without reference to an auxiliary fastener called

a lock nut. Figure 15 shows the standard shape of such a nut. Its purpose is to keep the tightening nut from turning on the bolt after it has been set, a function which it performs admirably. In design, no allowance is made for the reduced stress in the tightening nut; hence it is kept at its usual thickness. The lock nut should be on



FIG. 15. Common lock nut.

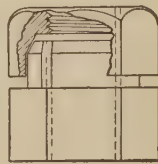


FIG. 16. Cottered and grip lock nut.

top or underneath the tightening nut, depending upon the pressures developed between the nuts and between the lower nut and its bearing surface. Variations in lock nut designs are also shown in Fig. 16. Their representation on a drawing is quite like that of the ordinary nut.

**PIPE THREADS.** — The pipe thread used in this country is known as the Briggs Standard. It differs from the British pipe thread in that the sides of the thread form an angle of 60 degrees, while the British thread, which is built on the Whitworth system, shows

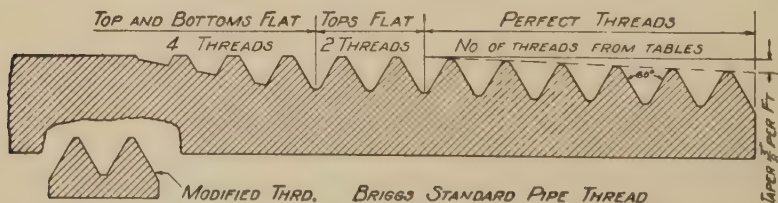


FIG. 17. Pipe thread profiles.

an angle of 55 degrees. The top and bottom of the standard Briggs thread are slightly rounded, although the difficulty of cutting such a thread has caused a modification of the form to that shown in Fig. 17. The bottom of the thread is made sharp and the top flattened as shown.

Pipe threads are cut on a taper of three-fourths of an inch to the foot, or in other words, one-sixteenth of an inch per inch. This causes a tight joint to be formed when a pipe fitting is screwed on to

the pipe, and it also allows the first few turns of the fitting to be made by hand. An enlarged profile of the end of a pipe threaded with standard Briggs threads is also shown in Fig. 17.

In specifying pipe threads, the inside nominal diameter of the pipe is given. A table of pipe sizes, including the number of threads per inch for each size of pipe, is to be found in the Appendix.

**RIVETS.** — These fasteners are universally used and are too well known to require descriptions. They differ in form from one another in the shape of the head only. Figure 18 shows the common shapes of heads and standard dimensions. The heads are simply pressed into any desired shape in proper machines, after the rod

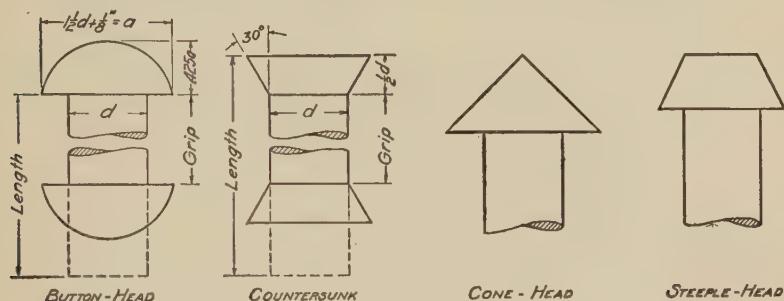


FIG. 18. Rivet head proportions.

has been heated. The unheaded end of the rivet must be heated when the rivet is used, and headed by hand or by pneumatic hammers or riveters as they are called. This headed end is called the "point," to distinguish it from the pressed head.

On a structural drawing, the head of the rivet is shown in one view only as a circle, and in some cases it is not shown at all. Rivet heads are represented by symbols, there being one for each of the several kinds of heads. Since the pieces held together by rivets may be joined in the shop where they are fabricated or put together in the field, we have a further symbolism to indicate which way the riveting is to be done. Also, rivet heads may be countersunk or chipped to provide for clearances, and symbols have been devised to show these things. These various kinds of symbols have been deftly combined, and reference to the complete chart of rivet symbols should be made by turning to Chapter XX, Part II, on Structural Drafting.

In boiler and tank work more pains may be taken to show the actual shape of the rivet head and the kind of joint desired. Ex-

amples of this kind of riveting are given in Fig. 19, where the ordinary butt or lap joints are frequently met with.

Both the diameter and length of rivets vary in increments of one-

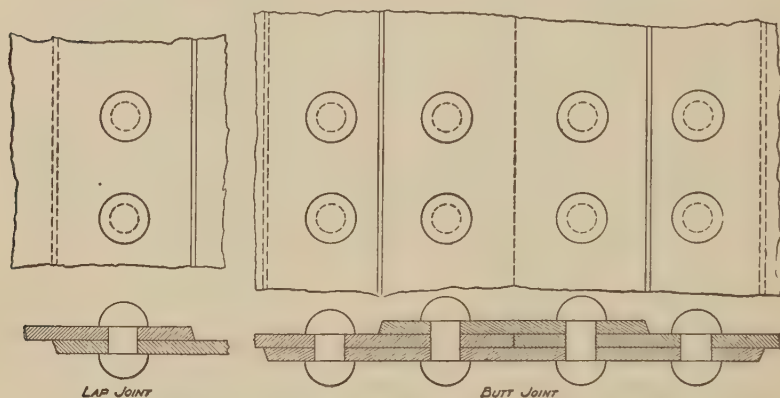


FIG. 19. Lap and butt joint riveting.

eighth of an inch, the former running up to one inch, the latter reaching as high as six inches. The rivet hole is punched a little

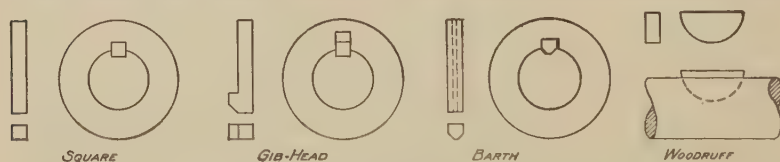


FIG. 20. Common keys.

larger than the rivet diameter and filled by the expanding rivet when headed.

**KEYS.** — Those fasteners called keys are chiefly used to hold pulleys and rocker arms on rotating shafts. There are several stand-



FIG. 21. Heavy-duty keys.

ard types, although the proportions of the keys themselves do not seem to have been built up from any very positive laws of design.

Figure 20 shows the four most common types. On drawings, all



keys and keyways should be shown. However, in the case of the Woodruff and Pratt & Whitney keys, dimensions should be omitted, and these keys should be specified by number and diameter

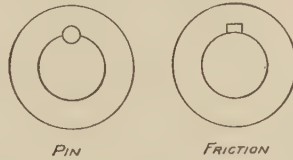


FIG. 22. Less common keys.

of shaft only. Any Mechanical Engineers' Handbook furnishes data as to the sizes of the various types of keys and the diameter of shaft with which each should be used. When heavy loads are to

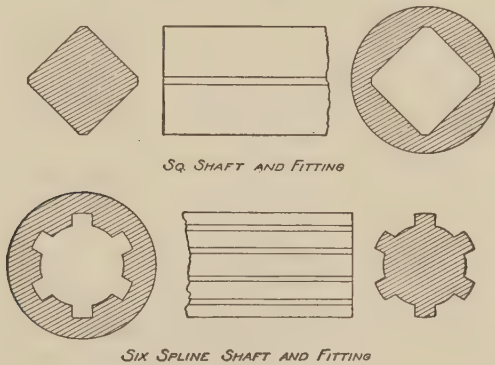


FIG. 23. Square shaft and multiple splines.

be transmitted from the shaft to the pulley or vice versa, two or more keys may be used, or the Kennedy and Lewis systems may be practicable. See Fig. 21. Other keys are shown in Fig. 22.

Of late, and especially in automobile work, keys have to a large extent been eliminated or supplanted by the square shaft and multiple-spline shaft fittings. Figure 23 illustrates these fastening devices.

## CHAPTER IX

### SHOP TERMS AND PROCESSES

The relation of the drafting room to the various shops is often underestimated in teaching the draftsman the technics of his profession. No design has commercial value unless the thing designed can be made in the shops, and at a cost that will allow it to compete with similar products in the markets. Odd size tools, impractical methods, and even impossible operations are often specified on drawings of the uninformed. The draftsman must know the capabilities and limitations of the shops. His drawings must "talk" in the shopman's language.

The best way for one to acquire intimate and accurate knowledge of the shops is through actual service in them. It is not possible nor desirable, perhaps, that everyone learning to do engineering work should serve apprenticeships in the shops. Everyone should, however, learn the fundamental shop processes, the names of machines and tools used, and the general advantages of one method over another. The four important shops are: pattern, foundry, forge, and machine shops. Those of a special character are omitted from consideration here, although most of them will be found to be equipped with standard machines used in the regular shops.

**PATTERN SHOP.** — The genesis of all cast metal work is found in the pattern shop. All drawings specifying castings must first go to the pattern-maker, who constructs a wood or plaster model of the thing to be cast. This model is called a pattern. Several important processes and shop terms used in the pattern shop will be briefly described.

**Pattern-maker's Rule.** — The draftsman gives dimensions on his drawing which are to be exactly those of the object after it is machined and polished. Since the casting shrinks as it cools, an allowance must be made for this in the pattern; hence, the pattern-maker's "shrink rule" is oversized an amount sufficient to take care of contraction. This oversizing is approximately equal to one-eighth of an inch in every twelve inches. The allowance for machining is made dependent upon the size and shape of the cast-

ing and also upon the method of machining. About one-eighth of an inch is allowed on small castings and as much as three-quarters of an inch on large castings. No reference to the shrinkage of the metal need be made on the drawing.

**Draft and Parting Lines.** — Casting molds are made up of sections which may be locked together in combinations of two or more for a single casting. Therefore, every pattern must be so constructed that at least one plane can be passed through it in such a way that, when this plane in the pattern is made to coincide with the plane between sections of the mold, the portions of the pattern on each side of this plane may be withdrawn from the sand in the respective sections without injury to the walls of the cavity left in each part. Sometimes the top surface of the pattern is put in the plane between sections, so that only one part of the mold will actually have an imprint of the pattern left in it when the pattern is withdrawn. In either case, a slight taper must be put on the pattern to allow it to be drawn out of the mold easily and without injury to the walls of the cavity. This taper is called the *draft*, or *draw*, of the pattern. Sometimes the pattern itself is made in halves.

From the above it is easily seen that any design of an object must be so made that at least one "parting" plane can be found on the object; or it must be such that the pattern of it can be placed in one section of a mold and drawn out as previously explained. The line on the drawing which indicates this dividing plane in the first case is called a *parting line*. In the second case, this line would be on an outside edge of one of the views. The draftsman does not put these lines on the drawing, but he must be sure his design is such that the pattern-maker may do so. Several parting lines may be used in making a single pattern.

**Fillet.** — Sharp angles on a casting are places of weakness. To strengthen these angles extra metal is provided; this process is called filleting the casting. On the pattern this takes the form of quarter-rounds of wood or leather nailed into these angles, as shown in Fig. 1. Wax is often used for this purpose. Simply rounding outside corners on a casting is not filleting.

**Core.** — In many castings, large holes are desired or interior passageways are needed. To avoid boring or machining operations, or where both of these are impossible, cores are inserted in the molds before the molten metal is poured into them. These cores occupy the places in the mold where openings are desired in the

casting. They are made of a specially prepared mixture of sand and binding material and are then burned hard in a core oven. When the pattern is withdrawn from the mold, these cores are inserted and held in place by small extensions or arms, which fit into

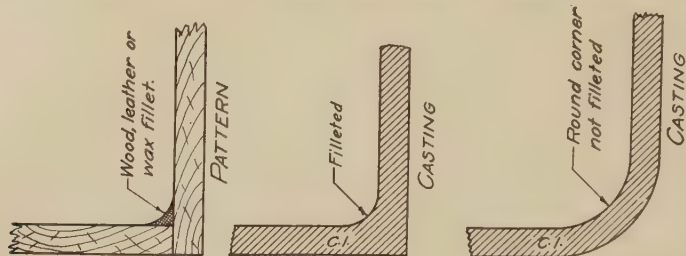


FIG. 1. Fillet on pattern and casting.

holes left in the walls of the sand by projections on the pattern provided for this very purpose. These projections are known as *core prints* and are simply dowels projecting from the proper places

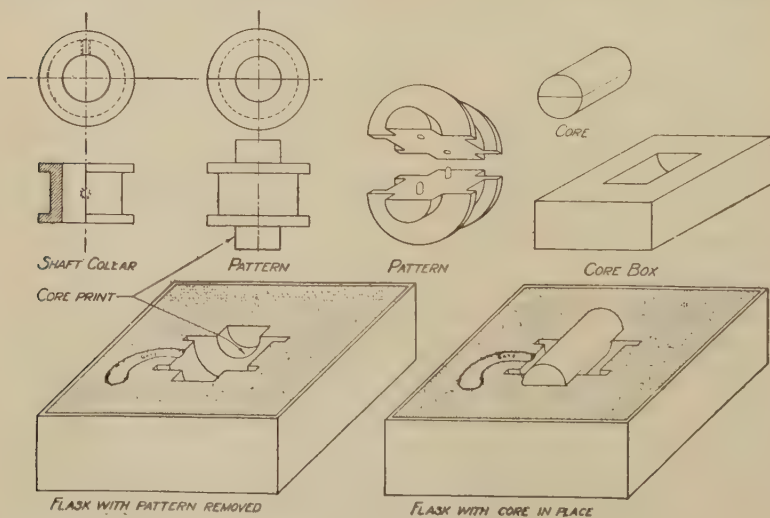


FIG. 2. Pattern, core, core-box, and flask.

on the pattern. Figure 2 illustrates these several relations of pattern, core and mold. When the metal has cooled, the cores are easily disintegrated and shaken out of the castings.

**Core Box.** — The wooden mold in which the core is made is called the core box. It is constructed by the pattern-maker, while the core is made by the foundry molder.

**FOUNDRY.** — The draftsman has little immediate connection with the foundry, since the pattern-maker acts as an intermediary between him and the molder. He should, nevertheless, acquaint himself with the machines and materials with which the foundry is equipped, chief among which are, of course, the cupola, the molding sand and the mold. The mold is generally made in two parts, although three and four parts are sometimes used. The bottom part is known as the drag, the top part as the cope, and the two together are called the flask.

Shop drawings do not, as a general rule, include any reference to foundry operations. However, there probably is no place where the item of cost is of more vital importance than in the foundry. Excessive metal and difficult shapes to cast are things which make the manufactured product costly, and the designer must always be on guard against these expensive items.

**FORGE SHOP.** — Many parts of a machine or structure cannot be cast, but have to be rolled, pressed, or forged into shape in the respective shops. Several forge-shop terms may occur on any drawing. Heat treatments of metals are included, because in many plants these treatments are considered a part of the forge-shop activity, as a matter of convenience and economy.

**Drop Forging.** — Instead of hammering the heated metal into the proper form by manipulation on the anvil, the forge man may use a die or mold of the desired shape, into which the heated metal is forced by means of drop hammers. The process may be considered a semi-casting scheme, in that the heated metal is made to conform to a desired shape in a mold. The character of the metal used, however, is entirely different from the casting metal used in the foundry.

**Tempering.** — Steels that have been worked on the anvil under the hammer, after repeated heatings, perhaps, are soft and unfit for cutting purposes until tempered. This is done by heating them to a temperature near "cherry red" (about 1600 degrees Fahrenheit), dipping, then allowing them to cool to about 500 degrees, and finally plunging (quenching) them into baths of water or oil. Steels that have been tempered may have the temper "drawn" by heating as before and then allowing them to cool without quenching. The character of the temper of any steel depends upon the temperature at which it is quenched. Although there are numerous methods of refining the tempering process, and although a good deal has been written which those most interested should



know, the draftsman need only indicate on his drawing the nature of the work which the part to be tempered must do, and the shop man will provide the right degree of hardness.

**Annealing.** — As in tempering, one of the objects of annealing is to make a hardened steel softer and less brittle. In addition to accomplishing this end, the method of heating and cooling removes all temperature stresses that may have been set up in the metal upon its first treatment. This result is obtained by slow and even heating of the steel in specially prepared boxes or beds of sand, powdered charcoal, and the like, and then allowing it to cool slowly in similar beds of charcoal or other slow heat-conductors. Molten lead and heated oil baths are often used for heating the steel.

**MACHINE SHOP.** — It is with the machine-shop processes that the draftsman must be most familiar. Shop tools, machines in which they are used, and the modes of operation of the machines have their limitations and possibilities. Some of the more important machines are drill presses, lathes, grinders, shapers, planers, milling machines, etc. A brief explanation of the purpose of each machine and the method of indicating its use on a drawing are given hereafter. The tools to be used and the manner of indicating their sizes are also included.

**The Drill Press.** — A common type is the radial drill press, in which the drill proper is held in a chuck, which in turn is mounted on an arm that can be revolved around and moved up and down on a vertical central axis of the machine. The chuck is given a horizontal motion on its carrying arm by means of a screw and gear arrangement, so that it is possible to drill a hole in almost any part of a rather large piece without reclamping or moving the piece about on the bed of the machine. The cutting tools used in a drill press are called drills. The simple drill press without a swinging arm is a requisite to any shop and is familiar to all. These machines are used for reaming and counterboring, as well as for drilling.

**Drills.** — The ordinary twist drill, the outlines of which are shown in Fig. 3, is familiar to everyone. When used to precede a thread tap, it is termed a tapping drill, or simply a tap drill. It is specified on a drawing by giving its diameter only. The noun or verb may be used to specify the size, thus, "Drill  $\frac{5}{8}$ " or  $\frac{5}{8}$ " drill." Drills up to 3 inches in diameter and 14 inches in length are obtainable. Below  $\frac{1}{4}$  inch, the sizes are given by numbers only.

**Reamers.** — A hole that has been drilled is left with a rough and slightly scored surface. It is not suitable for close fits or for tapping if fine thread crests are desired. The reamer is used to finish and smooth this rough surface. There are several types of reamers, but most work is done with the fluted reamer shown in Fig. 3. The draftsman indicates the ream to be used by giving the diam-

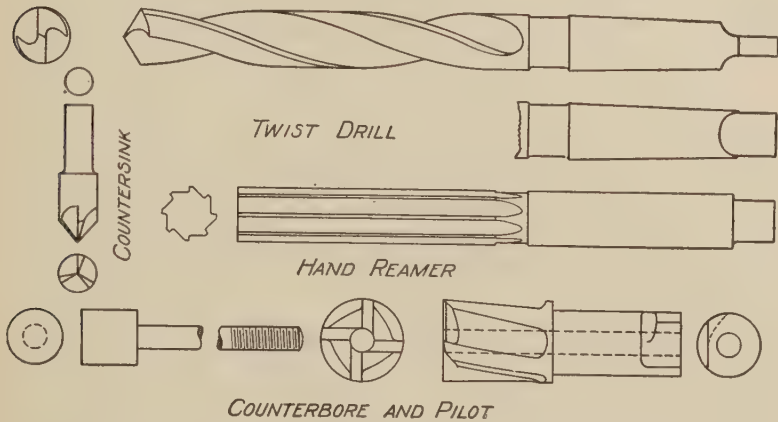


FIG. 3. — Drill, reamer, counterbore, and countersink.

eter of the finished hole and omitting the drill diameter, thus, "Ream to  $\frac{5}{8}$ ", or  $\frac{5}{8}$ " ream." Reamers up to 3 inches in diameter and 17 inches in length can be secured.

**Boring.** — Closely associated with the process of drilling and reaming, in respect to the results achieved, is that of boring. The operation is done on a lathe or specially designed boring machine, and consists of making a round hole in a piece of considerable length or size, such as an engine cylinder or gun barrel. Very small holes can be bored, and all holes beyond the sizes and lengths of drills and reamers must be bored. The cutting tool is held on a boring bar which advances into the bored hole as the piece itself or as the boring tool is revolved. The note on the drawing to indicate the boring process simply gives the diameter of the finished hole and the name of the operation, thus "3" bore."

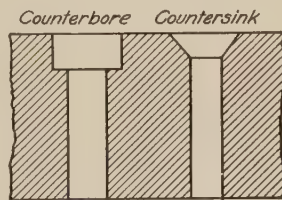


FIG. 4. Counterbore and countersink holes.

In some instances a counterbore is indicated, in which case the depth must also be given, thus, "4" counterbore,  $3\frac{1}{2}$ " deep." Heads of bolts and screws are brought level with the surface of parts through which they pass by counterboring a hole larger than the drill or tapped hole a depth equal to the height of their heads. This is usually done on the drill press.

• Heads of screws with tapering sides are brought level with the surface through which they pass by countersinking instead of counterboring. Figure 4 shows the result of the two operations.

**The Lathe.**—The lathe is the most generally used machine in the shop. Practically all machining of cylindrical surfaces such as spindles, glands, etc., is done on the lathe. The piece to be machined is supported between two centers, one in the tailstock, the other in the headstock, and then revolved by power supplied through the headstock. A tool post, which may be moved longitudinally along the lathe, carries the cutting tool, which removes a thin layer of metal each time it traverses the length of the surface being machined. The operation is called turning, and the draftsman generally uses this term on his drawings in specifying the operation, if any mention of the process is made at all.

Other things besides turning may be done on a lathe, such as boring, already alluded to, grinding, reaming, knurling, threading, and polishing.

**Grinding.**—Grinding machines may vary from the ordinary coarse and fine emery wheels to high-speed abrasive wheels like those made of carborundum. The purpose of grinding is to leave a finished surface on the metal, and at the same time to economically remove the small amount of stock left after the last rough cut in the lathe has brought the size to within  $\frac{1}{32}$  or  $\frac{1}{64}$  of an inch of the required size. In other words, the draftsman indicates the grinding operation on his drawings when he wants the outer surfaces left smooth and to an exact size, say within one one-thousandth of an inch. Both external and internal grinders are available, and although both the grinder and piece being ground are usually revolved against each other, stationary surfaces may also be ground.

**Polishing.**—Polishing must not be confused with grinding. Although a ground surface is very smooth, it is not said to be a polished surface until it has been gone over carefully with a fast-revolving disc of material like muslin or leather, which gives it a luster impossible to attain with the finest grinders. The draftsman indicates such an operation by the note, "grind and polish."

**The Milling Machine.** — The milling machine is like the ordinary rotary saw seen in lumber mills and wood shops, in its manner of operation. The cutters are circular discs, with teeth which cut away the metal from any piece as it is automatically fed along under the revolving cutter. Slots, keyways, gear-teeth, and similar cuts are easily made with the milling machine. End mills, for such work as finishing ends of bosses and bearings, are available in the average shop. Both the diameter and width of the milling cutter should be specified on the drawing.

**The Planer.** — When large, flat surfaces are to be finished, a machine called a planer is used. The piece to be planed is mounted on a long horizontal bed which moves the surface of the piece forward and backward under the cutting tool, which in turn moves laterally a small amount, each run of the bed. Numerous pieces of the same kind may be clamped to the bed and planed at once. The draftsman makes no reference to this machine on his drawing, but simply writes the word "finish," on the surface to be planed or uses the small letter *f* as previously explained.

**The Shaper.** — Although it is like the planer in the respect that surfaces are machined by a relative motion of the cutting tool and the piece being finished, the shaper is arranged in such a way that the tool is the fast-moving part and the bed is governed by the operator, which, of course, is the reverse of the scheme employed in the planer. The shaper is particularly adapted to the cutting of slots and grooves, and to general utility finishing work. The draftsman simply indicates the surfaces to be finished or the kind of groove to be cut, without referring to the shaper itself in putting notes on his drawing.

**Jigs and Fixtures.** — In operating machines in the shop it is necessary to repeat the same operation scores of times in identically the same way and to exactly the same dimensions, on a part that is being turned out in quantities. No shopman could accomplish this task with rule and calipers only, and maintain standard conditions. Devices known as jigs and fixtures overcome the difficulties of inexact measurements and greatly shorten the time of operation.

There is often a question as to which one of these devices is being used, since in many instances their functions are identically the same. In general, we may say that the fixture is fastened rigidly to the machine and serves to hold the work in place, while the tools are doing their work; hence the name fixture. A jig, on the other

hand, may be held on the work, or it may hold the piece being machined and at the same time act as a guide for the tools.

Up-to-date shops have their own designer of jigs and fixtures, and the draftsman need not pay attention to these devices in turning out machine drawings.

**Broaching.** — In cutting internal slots, plane square and rectangular holes, holes for splines, etc., a tool called a broach is used. This tool is simply a stiff, hard-tempered shaft of steel, of a shape to cut the required hole, with cutting teeth along each side. The broach is either pushed or pulled through a round hole which has been previously drilled, and the interior of the hole is left smooth and of the desired shape. When a push broach is used, some type of press, either hydraulic or otherwise, is provided, while for the pulling broaches a standard broaching machine has been devised in which the force is applied through a screw.



## CHAPTER X

### PICTORIAL DRAWING

Two- or three-view orthographic projections of objects are unintelligible to many people who have had no training in the art of drawing, because the drawings bear so little resemblance to what the eye actually sees. Two- or three-view drawings show only one face, and give only two dimensions of an object at a time, with no idea or suggestion of depth, while the eye ordinarily sees three sides of an object at once. Hence, if a drawing is made that presents three sides of an object in one view, it becomes easily readable and conveys a definite meaning to the average person. Even by the man who is trained in reading drawings, the true relation of parts can be more readily and quickly grasped from a pictorial representation than from ordinary working drawings. In order to present three-dimensional objects in this way, different pictorial schemes are commonly employed, called isometric, oblique, and perspective drawing.

All of these schemes possess the advantage of presenting three faces of an object in one view; but, combined with this advantage, are certain disadvantages which seriously limit the use of pictorial drawing for the engineer:

1. It is more difficult to dimension isometric and oblique drawings than the usual three-view drawings, while perspective does not lend itself to dimensioning at all.

2. Although isometric drawings can always be scaled, oblique drawings may be scaled only under certain conditions, and perspectives can never be scaled.

3. The time required for the execution of pictorial drawings is much longer than for two- or three-view drawings, except in the case of very simple objects.

4. Isometric and oblique views sometimes have a distorted appearance which is very disagreeable, because the receding lines on the drawing are parallel, while to the eye the receding parallel lines which they represent actually appear to converge.

In spite of these disadvantages, however, the fact that ideas may

be presented in a form which all can understand makes a thorough knowledge of the fundamentals of pictorial drawing almost indispensable to the engineer.

**USES.** — The architect and architectural engineer make very frequent use of perspectives, to study the form and proportions of a building, and also to give to their clients an idea of the appearance of the finished structure. Isometric drawings are often used in making piping and wiring diagrams. Both isometric and oblique drawings are sometimes used for shop purposes, especially where there are workmen who are not skilled in reading working drawings. For patent office drawings and for advertising and display purposes, any one of the three schemes may be used to advantage.

**METHODS.** — As has been stated, all pictorial drawings are one-plane drawings. For convenience, the vertical plane is chosen as this *picture plane*, although for purposes of explanation other planes are used. Three distinct methods are employed to obtain the three kinds of pictorial drawings named in the preceding paragraph:

1. The object may be turned in respect to the principal coördinate planes in such a way that, when projected orthographically upon any one of them (usually the vertical), three faces of the object will be shown in one projection. This method gives what is termed *axonometric projection*, which in turn is subdivided into isometric, dimetric, and trimetric projection, depending upon the position of the object relative to the plane of projection.

2. Instead of turning the object from its customary position relative to the principal coördinate planes, the parallel projecting lines are made to intersect the plane of projection obliquely, instead of at right angles as in orthographic projection. This, in effect, is changing the point of sight, and obviously accomplishes the purpose of showing three faces of the object at one time.

3. The third method consists of moving the point of sight a finite distance from the picture plane, the object remaining in its usual position relative to the plane, or being rotated on a vertical axis some predetermined angular amount. The projecting lines converge, of course, on this finite point of sight. In the first case the result is called *parallel or one-point perspective*; in the second case the result is called *angular or two-point perspective*.

The table below is a classification of the various kinds of projection used in mechanical drawing. It gives briefly the salient features of each of the types and shows their relation to each other.

A careful study of the chart will fix in the student's mind the

whole fundamental theory of projection underlying the expression of ideas by means of the graphical language. As stated elsewhere in this text, the kind of drawing produced by the draftsman depends upon the simple relations existing between the object, the plane of projection, and the projecting lines or lines of sight. These relations are epitomized in the table.

CLASSIFICATION OF PROJECTIONS USED  
IN MECHANICAL DRAWING

|                     |                                                                                                                                                              |                                         |                                                                                                                                                                                                                           |
|---------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mechanical drawing. | Orthographic projection.<br>Point of sight at infinity.<br>Projecting lines at right angles to the plane of projection.                                      | Polyplane Projection.                   | Two- and three-view drawings.<br>Faces parallel to the planes of projection.                                                                                                                                              |
|                     |                                                                                                                                                              | One-plane projection.<br>(Axonometric.) | Isometric.<br>Faces equally inclined to the plane of projection.<br><br>Dimetric.<br>Two faces equally inclined to the plane of projection.<br><br>Trimetric.<br>All faces unequally inclined to the plane of projection. |
|                     | Oblique projection.<br>Point of sight at infinity.<br>Projecting lines oblique to the plane of projection but all making same angle with it.                 | One-plane projection.                   | Cavalier projection.<br>Angle of obliquity 45 degrees.<br><br>Cabinet drawing.<br><br>Pseudo-perspective.                                                                                                                 |
|                     | Scenographic projection.<br>Point of sight at a finite distance.<br>Projecting lines oblique to the plane of projection and making different angles with it. | One-plane projection.                   | Parallel or one-point perspective.<br>Object has one face parallel to the plane of projection.<br><br>Angular or two point perspective.<br>Object has two faces equally or unequally inclined to the plane of projection. |

*Note:* — This table does not include the various phases of map projection.

# CHAPTER XI

## ISOMETRIC PROJECTION

### SECTION 1

Isometric projection, while properly classified under the heading of orthographic projection, differs from anything studied heretofore in that only one plane of projection, called the isometric plane, is used. This plane makes equal angles with the three principal planes of projection, as shown in Fig. 1. Assuming a cube in the first quadrant in the normal position for orthographic projection, i. e., with the faces parallel to the principal planes, it is evident that one body diagonal of the cube is perpendicular to the isometric

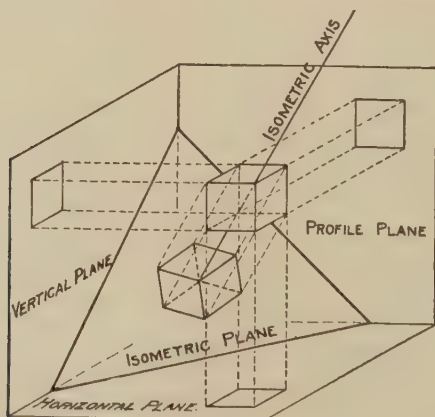


FIG. 1. The isometric plane.

plane. This body diagonal is called the *isometric axis*. The edges of the cube make equal angles with the isometric plane, and consequently, if projected upon it orthographically, will be equally foreshortened; hence, the projection is called an *isometric*, which means equal measurement. The point of sight is assumed to be on the isometric axis at an infinite distance from the plane. Therefore, an

*isometric of an object is an orthographic projection of the object on the isometric plane.*

In the actual construction of an isometric, however, it is not necessary for the student to visualize the isometric plane, for the object may be placed in the same position, relative to any plane, in which the cube described above is placed relative to the isometric plane. The vertical plane is perhaps the most convenient, and

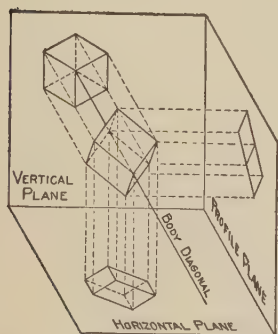


FIG. 2. Isometric projection on vertical plane.

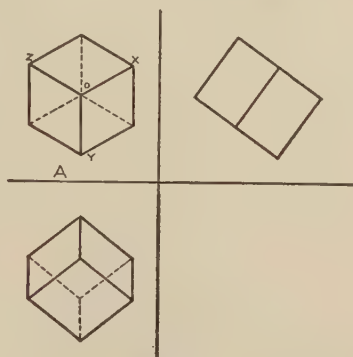


FIG. 3. Orthographic projections of cube, shown in Fig. 2.

hence is used as the isometric plane. The vertical plane is assumed to be the plane of the drawing paper.

If, therefore, a cube is so placed that one of its body diagonals is perpendicular to the vertical plane, the cube is evidently in the proper relation to that plane to produce an isometric upon it when projected by the usual orthographic method. Figure 2 shows a cube in this position, and Fig. 3 shows the three orthographic projections of the cube in the same position. The view marked A, — the vertical projection, is also the isometric of the cube.

**DEFINITION OF TERMS.** — The projection of the front corner of the cube is called the *origin*, and is indicated by *O* in the isometric *A* of Fig. 3. The projections of the three front edges of the cube, *OX*, *OY* and *OZ* are called the *isometric directrices*. All lines on the cube parallel to these three edges are called *isometric lines*. Since the edges of the cube make equal angles with each other and with the body diagonal of the cube, their projections on any plane make equal angles with each other when the body diagonal is perpendicular to the plane. Thus, angle  $ZOX = \text{angle } XOY = \text{angle } YOZ = 120^\circ$ . The planes of the three



faces of the cube are called *isometric planes*. Any planes parallel to these three are also called *isometric planes*.

**ISOMETRIC SCALE.** — From Fig. 3 and the discussion in the preceding paragraph, it is clear that the lines of the isometric are all shorter than the actual lengths of the edges of the cube. The angle which the edges of the cube make with the plane of projection is  $35^{\circ} 16'$ , so that the projections are about eight-tenths of the true length of the lines. In order to make an isometric of an object which shall be mathematically correct, it is necessary to construct a special scale, called the isometric scale, on which all units of measurement have been foreshortened in the same ratio as were the edges of the

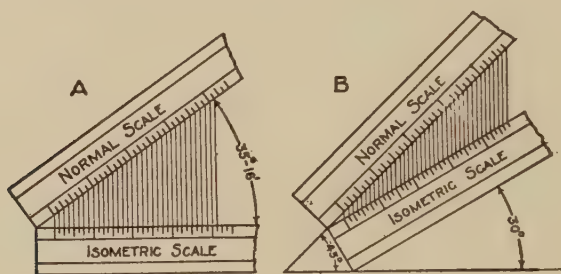


FIG. 4. Isometric scale.

cube when projected on the isometric plane. Two methods for constructing such a scale are shown in Fig. 4, A and B.

To construct an accurate isometric, therefore, two scales must be used, — the one a normal scale with which to measure the object, the other an isometric scale with which to make the drawing. This is very inconvenient, and such a drawing would be impractical since it could not be scaled in the shop or elsewhere without an isometric scale. For this reason, *isometric drawings* are seldom real projections of objects, but are about one and one-quarter times larger in linear dimensions than the true projections, because made with the normal scale. Thus, by disregarding all foreshortening of lines, yet retaining strict ratios of lengths and the same proportions, we are able to produce a useful and effective drawing for ordinary purposes with a minimum expenditure of the draftsman's time. To avoid confusion and error, drawings made upon isometric principles, but without the use of an isometric scale, are termed *Isometric Drawings*, while real projections, or those on which an isometric scale is used, are termed *Isometric Projections*.

**ISOMETRIC DRAWING OF A CUBE.** — To make an isometric drawing of a cube, a convenient point on the paper may be selected as the origin, and from this, by means of a T-square and a  $30^{\circ}$ - $60^{\circ}$  triangle, the three axes or front edges may be drawn, one vertically, one up 30 degrees from the horizontal to the right, and one up 30 degrees from the horizontal to the left. Along these three lines the actual length of the edges of the cube may be measured to any convenient scale. From the three corners thus located, the remainder of the cube may be readily obtained with the  $30^{\circ}$ - $60^{\circ}$  triangle by paralleling the three lines already drawn. See A, Fig. 3.

**DRAWING OF PLANE FIGURES.** — The isometric drawing of a solid object consists mainly in representing three more or less broken plane faces, which are parallel to isometric planes and in which there may be several non-isometric lines. The outlines of the

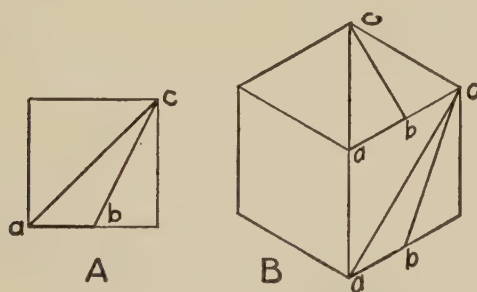


FIG. 5. — Isometric of triangle.

plane faces with the non-isometric lines in them, constitute a series of plane geometrical figures which must be drawn in isometric. Hence, the drawing of plane figures will be considered first.

Let it be required to draw a triangle in an isometric plane. Lay out the triangle and enclose it in a square, as in A, Fig. 5. Then draw the square in isometric as if it were any one of the three faces of a cube, and locate the three corners of the triangle in this square by measurement. Thus, in B, Fig. 5, *a* and *c* are at opposite corners of the square, and *b* is located by measuring from *a* in the isometric square a distance equal to *ab* in the true square. If the triangle could not have been enclosed in a square, an enclosing rectangle could have been drawn and the procedure would then be the same as in the square.

To draw an octagon in isometric, proceed in the same general manner as with the triangle above, first enclosing the octagon in a square, as in *A*, Fig. 6. Then draw coördinate lines through the points of the octagon which do not lie on the sides of the square. Draw the square in isometric and rule in the coördinate lines by means of measurements along the isometric axes, thus locating the corners of the octagon. See *B* Fig. 6. By drawing lines from point to point, the octagon may be constructed.

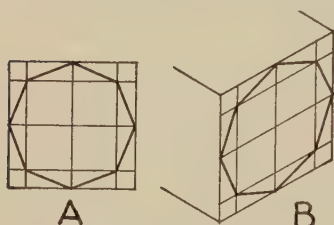


FIG. 6. Isometric of octagon.

A circle or any irregular plane figure may be drawn in isometric by the coördinate method described above. Figure 7 shows which the actual steps of construction are self-evident. The curves, of course, must be drawn through the plotted points with the aid of an "irregular" curve.

A circle may also be drawn in isometric by the approximate method shown in Fig. 8. First, draw the long diagonal of the isometric square which encloses the isometric of the circle. Then

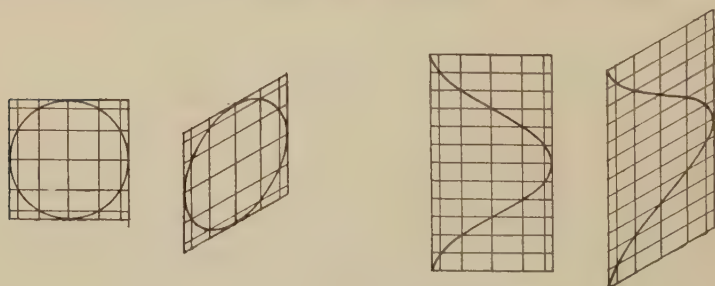


FIG. 7. Isometries by coördinate method.

from each one of the remaining corners draw lines to the mid-points of the opposite sides, as  $df$  and  $ce$ . The intersection of these lines with the long diagonal  $km$  locates the centers,  $a$  and  $b$ , of the small arcs. With  $b$  as a center and  $bf$  as a radius, draw the arc  $fh$ , and with  $a$  as a center and the same radius, draw the arc  $ge$ . With  $c$  as a center and  $ce$  as a radius, draw the arc  $eh$ , and repeat the operation with  $d$  as a center, thus completing the circle in isometric. The method involves less labor than the coördinate method and is sufficiently accurate for all practical purposes.

From the drawing of plane figures to the drawing of solid objects in isometric, is but a simple step, involving only the drawing of a third coördinate. First, imagine the object enclosed in a rectangular box; then make a two- or three-view drawing of both the object and the enclosing box, as illustrated in Fig. 9. This may not always be necessary, but for an object containing a great many non-isometric lines, it is the most practical method of approach. It should be noted that the scale used on the two- or three-view drawing need not be the same as that used on the isometric, except on curved figures. Also, the scale to be used on the isometric need not be the normal inch-to-the-inch, but any scale suitable to the size of the object and paper.

The hexagonal base of the truncated pyramid may be drawn in by the methods discussed under isometric drawing of plane figures. All lines in the base of this figure, with the exception of two, are non-isometric, and therefore no measurement can be made on these lines themselves. After the base has been drawn, it is only necessary to locate the six points of the truncated face and then connect them with the proper

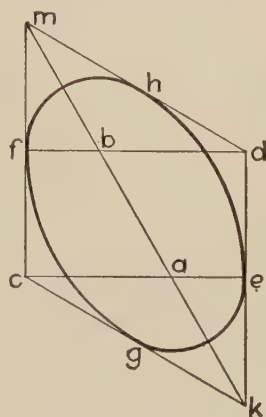


FIG. 8. Four center method.

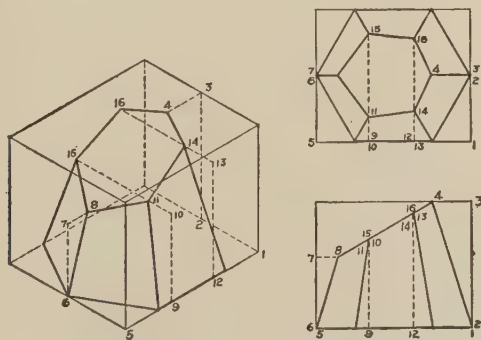


FIG. 9. Solids in isometric.

points in the base and with each other, to complete the figure. Since this face does not lie in an isometric plane, a third coördinate measurement is necessary for each point.

For example, to locate point 4, it is necessary to measure off the

three coordinates 1-2, 2-3, and 3-4. The length of these coordinates is obtained from the two-view drawing, and the measurement made along isometric lines, beginning at the corner of the box marked 1 and laying off 1-2 along the lower rear edge. Then 2-3 is laid off vertically and 3-4 is laid off in the proper direction in the upper face of the enclosing parallelopiped.

Point 14 may be located in the same manner by laying off the coordinates 5-12, 12-13, and 13-14, or the coordinates 1-12, 12-13,

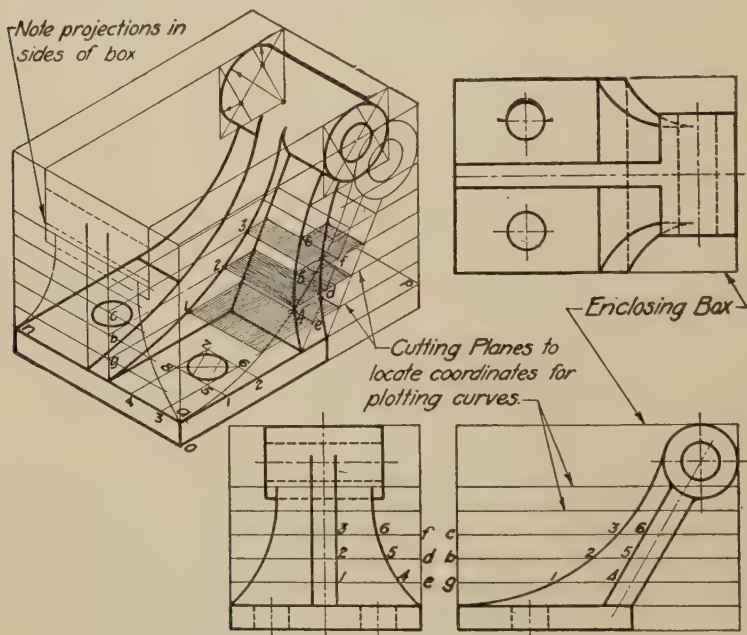


FIG. 10. Isometric planes of construction.

and 13-14. The method of measurement is clearly indicated in the figure for all of the points. For further illustrations of isometric constructions see Figs. 4, 5 and 6, Chapter V.

After the entire construction has been completed in light pencil lines, the visible lines of the figure may be made heavier or inked in, after which the construction lines should be erased. It is customary in isometric drawing to omit all hidden lines except where they may be necessary to make clear the construction of the object.

It will be observed in the above construction that all measurements are made along isometric lines only. This point should be carefully noted, because measurements made in any other way will be in error, for the isometric lines are the only lines of equal fore-



shortening or equal measurement. Any violation of this rule will lead to failure.

The simple bearing shown in Fig. 10 will serve to further illustrate isometric construction. Considerable time can be saved in drawing, if the draftsman recognizes that a great deal of the construction of an object falls naturally into several isometric planes. For example, the holes in the base of the bracket bearing have the construction of the circles representing their upper edges entirely in the plane  $n-a-p$ . If the coördinate  $oa$ , representing the thickness of the base, is laid off, and the plane  $n-a-p$  drawn in lightly, the remainder of the construction can then be measured along isometric lines lying in this plane. Thus, the coördinates  $a-1$ ,  $a-2$ ,  $a-3$ , and  $a-4$  can be laid off, and the parallelogram  $5-6-7-8$  for one of the circles can be readily found.

A careful examination of this figure will show the various planes of construction used and the general method of procedure. Much of the work shown in the figure would be unnecessary to the skilled draftsman in making an isometric of such a simple object. Many short cuts will suggest themselves to the thoughtful draftsman who thoroughly understands the principles of isometric projection. To this end, the habit of visualizing and carrying on the construction in isometric planes, as indicated in the figure, will be found helpful.

To draw curved lines other than circles, or circles which do not lie in isometric planes, it is necessary to plot a number of points on the given lines and then draw a smooth curve through them.

**DIMENSIONING.** — For shop purposes, an isometric drawing must be dimensioned. The regular rules and suggestions for dimensioning two- or three-view working drawings hold for isometric drawing in a general way; but, in addition, the following rules must be observed:

1. Dimensions on isometric drawings should be placed in such a way that they can be read from one point of view, which should be from the bottom of the sheet. This may be said to encompass all other rules in regard to the direction in which dimensions should read, and it is the only safe one to follow at all times.

2. All dimension lines must be isometric lines, and the figures and letters should be made to lie in isometric planes. Only the vertical style lettering should be represented in isometric drawing. This means that axes of letters and horizontal strokes must be kept parallel to corresponding isometric lines. In the case of circles and arcs, where isometric lines cannot be used conveniently, the

dimension lines must lie in an isometric plane. An illustration of dimensioning in isometric is shown in Fig. 11.

**SCREW THREADS.** — Screw threads can be drawn in isometric, but the process is so laborious that a conventional scheme has been

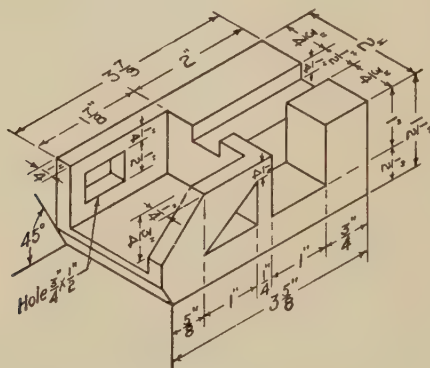


FIG. 11. Dimensioning in isometric.

adopted. Arcs of circles are used to represent the crest and root of the thread. These arcs may be drawn by the approximate

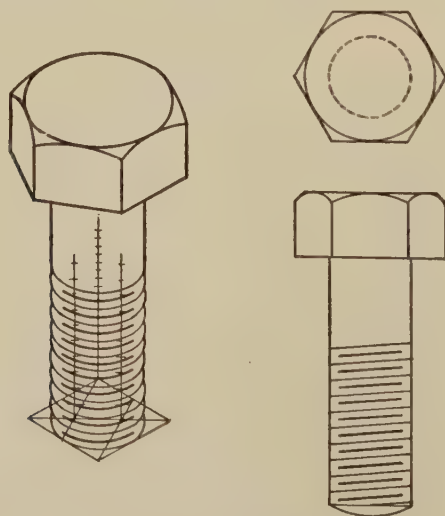


FIG. 12. Threads in isometric.

method, and only three of the four centers need be found. See Fig. 12. The first arc is drawn, and then centers for the remaining arcs are laid off on the line of centers, according to the pitch of the thread.

**SECTIONS.** — Sections are frequently necessary in isometric drawing, especially if the interior construction of some object is to be shown without using hidden lines. Half or full sections may

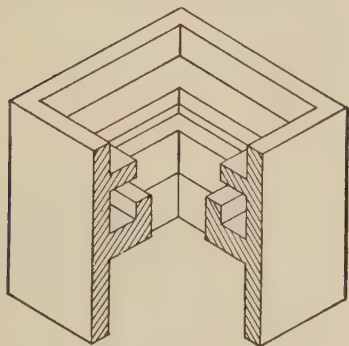


FIG. 13. Sections in isometric.

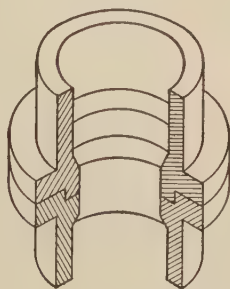


FIG. 14. Poor section lining.

be made, just as in a three-view drawing. The cutting planes are usually isometric planes. Figure 13 illustrates a section in isometric. Care should be exercised in cross-hatching to give the effect of superposition of lines, if the two surfaces on which the section lines fall should be revolved together. Figure 14 illustrates the poor effect produced when attention is not given to this phase of isometric drawing.

**POSITION OF DIRECTRICES.** — Thus far we have considered isometric drawing with the object always in one particular position.

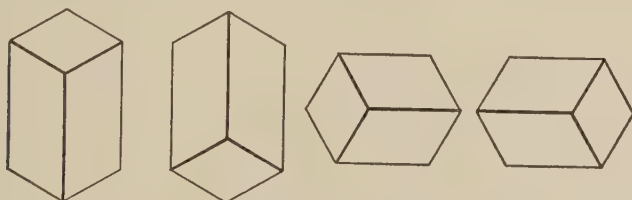


FIG. 15. Convenient positions of isometric axes.

The directrices, however, may be drawn in four positions, which permit different sides of the object to be shown. The rectangular box shown in Fig. 15 illustrates the four customary positions of the directrices.

## CHAPTER XI

### DIMETRIC AND TRIMETRIC PROJECTION

---

#### SECTION 2

An axonometric projection of an object is an orthographic projection (projecting lines perpendicular to the plane) upon a single plane, showing three faces of the object in one view, with the principal coördinate axes foreshortened by varying amounts according to the different arrangements of the axes in respect to the plane. If the foreshortening is the same on all three axes, the projection is called *an isometric*; if two axes are foreshortened equally and the third by a different amount, the projection is called *a dimetric*; and finally, if the foreshortening on all three axes is different, it is called *a trimetric projection*.

The same distinction is made between dimetric or trimetric projection and dimetric or trimetric drawing as was made in Section 1 of this chapter between isometric projection and isometric drawing. In ordinary work no attempt is made to find the correct scales or even the exact ratios of the scales, because it is just as unnecessary and inconvenient as in isometric drawing.

The chief point of variation among the three divisions of axonometric drawing is not so much in the scales used or in the foreshortening as in the angles between the axes. In the case of isometric, the three angles are equal; in dimetric, only two are equal; and in trimetric, all three have different values. In no case can the value of any angle be 90 degrees.

With objects of cubical shape, there is an exactness of symmetry and an overlaying of lines in different planes, in an isometric, which is sometimes confusing and often makes the drawing impossible of interpretation. This difficulty may be overcome by making a dimetric instead, thereby very frequently lessening the appearance of distortion. The dimetric scheme is very often employed in freehand sketching.

**DIMETRIC PROJECTION.** — The underlying principles in dimetric projection may be best explained by means of a few figures.

If we assume a cube in the proper position for isometric projection — the dotted projection in *A*, Fig. 1 — and then imagine it to be rotated any desired angle, about a horizontal axis through the front corner and parallel to the *V*-plane, to the position shown by the solid lines, it is then in a suitable position for dimetric projection upon the plane. The cube may be rotated upward instead of

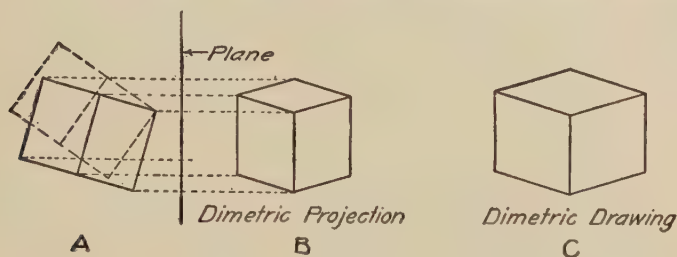


FIG. 1. Dimetric projection, cube rotated down.

downward, as shown in Fig. 2. The cuts marked *B*, in Figs. 1 and 2, are both exact dimetric projections, while those marked *C* are dimetric drawings, made by using the same scale on all axes. Both of these appear somewhat out of proportion, and a better result could have been obtained by using two scales which would roughly approximate in ratio that of the correct scales.

The method of rotating the cube in Figs. 1 and 2 is most readily comprehended, but it must not be assumed that the cube can only

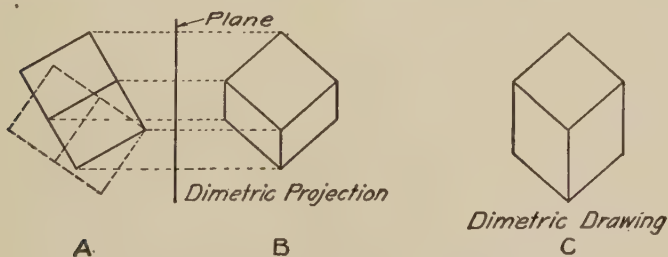


FIG. 2. Dimetric projection, cube rotated up.

be rotated in the manner shown. The angles between the axes may have any values except 90 and 120 degrees, and the axes may be drawn in any direction on the paper, though one of the axes is usually vertical. Figure 3 shows the cube rotated about a horizontal line parallel to the *V*-plane until its front edge makes an angle of 15 degrees with the plane, and then rotated about this



edge as an axis until one of the upper front edges makes the same angle with the plane. The steps of construction and the resulting dimetric are shown in Fig. 3, *A*, *D*, and *B*. The ratio of the scales in the projection is very nearly  $1:1:\frac{3}{8}$ . A better result, however, is obtained in *C* by making a drawing in which the same angles are used but the scale ratio is changed to  $1:1:\frac{1}{2}$ .

As has been pointed out in a preceding paragraph, the angles between the axes in dimetric may have any values except 90 and

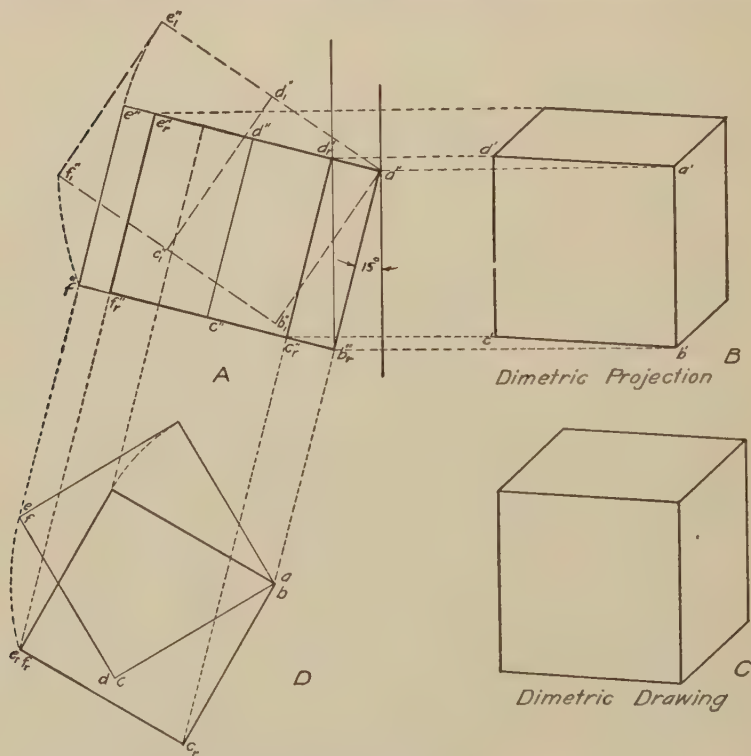


FIG. 3. — Dimetric projection, double rotation.

120 degrees. A satisfactory dimetric drawing may be made by following out the same principles of construction used in isometric drawing, which may be briefly summarized as follows: First, select the position of the axes to give the desired view, and choose two scales which will give the best appearance. Second, in conformity with these scales, draw a box that would just enclose the object, and then proceed by locating control points exactly as described in isometric drawing.

As a suggestion in selecting the scales, the following list may be helpful. In dimetric, of course, two of the angles are equal.

|                                |         |             |                               |
|--------------------------------|---------|-------------|-------------------------------|
| Equal angles, each 132 degrees | .....   | Scale ratio | $1:1:\frac{1}{2}$             |
| "                              | " 126 " | .....       | " $1:1:\frac{3}{4}$           |
| "                              | " 107 " | .....       | " $\frac{3}{4}:\frac{3}{4}:1$ |

The limiting values of all ratios in dimetric drawing are  $1:1:0$  and  $.7:.7:1$ .

**TRIMETRIC PROJECTION.** — As may be inferred from the name, trimetric projection requires that the three edges of the cube shall

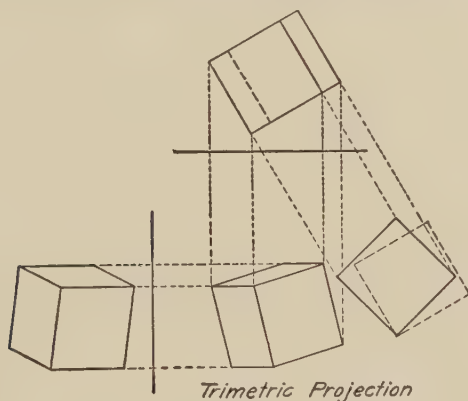


FIG. 4. Trimetric projection.

make different angles with the plane, and hence the angles between the projections of the axes are different. Figure 4 shows the construction for a trimetric. A satisfactory trimetric drawing may be made by selecting the direction of the axes and one, two, or three scales to correspond, as the effect desired may require, and then plotting in the same way as for isometric or dimetric. The practical value of trimetric drawing of this type is very small.

There is, however, a form of oblique projection, sometimes mistakenly called trimetric projection because each of the axes is foreshortened by a different amount, which is used as the basis for the drawing in the study of crystallography. A brief discussion of this variation of oblique projection may be found in the second part of Chapter XII.

## CHAPTER XII

### OBLIQUE PROJECTION

In both orthographic and isometric drawing, already discussed in this text, the projecting lines have been at right angles to the planes or plane of projection. We shall now consider a kind of drawing in which, as in isometric, only one plane of projection is used, but in which the projecting lines, although parallel to each other, are oblique to the plane of projection. The object may be placed in any position, but for convenience and to obtain the full advantage of this method of drawing, it is customary to have the front face parallel to the vertical plane which is used as the plane of projection, as in isometric drawing. The angle which the projecting lines make with the plane may be of any desired value except 90 degrees. When, however, the angle is chosen as 45 degrees, the drawing is called a *cavalier* projection, which, by virtue of the 45-degree angle, has certain advantages not obtainable when other angles are used. We shall fully consider, therefore, only cavalier projection and its modifications.

**CAVALIER PROJECTION OF LINES.** — Assume a vertical plane  $V$  as the plane of projection and a line  $AB$  perpendicular to it, with the end  $A$  in the plane and the end  $B$  lying behind the plane, as in Fig. 1. If the line  $AB$  is viewed from infinity in the direction of the projecting line  $a_1$ , which makes an angle of 45 degrees with  $V$ , then  $A$  and its projection on  $V$  coincide, and  $B$  is projected to  $B_1$ . Obviously, the projection  $AB_1$  is equal in length to the line  $AB$ . This relation holds true if the line  $AB$  is viewed from the direction of the lines,  $b$ ,  $c$ , and  $d$ , respectively, or from any other direction so long as the projecting lines or lines of sight, as they are called, make an angle of 45 degrees with  $V$ . Hence, in cavalier projection, any line which is perpendicular to  $V$  will project in its true length upon  $V$  regardless of the direction of the projecting lines, provided they make 45 degrees with  $V$ . The direction of the *projection* of a line on the plane relative to a horizontal or vertical line must not be confused with the direction of the *projecting lines* relative to the plane itself. Clearly, from Fig. 1, the projection of  $AB$  on the  $V$ -plane

may be in any position in the whole arc of 360 degrees around  $A$ , while the projecting lines will always make 45 degrees with the plane. The statements just made hold true for a line perpendicu-

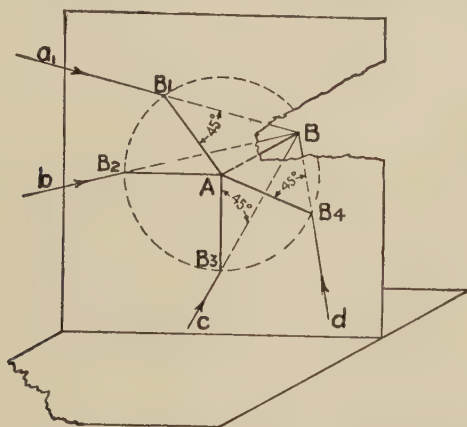


FIG. 1. Cavalier projection of line.

lar to  $V$  when neither end is in the plane of projection; but, of course, the projecting lines must be kept parallel to each other.

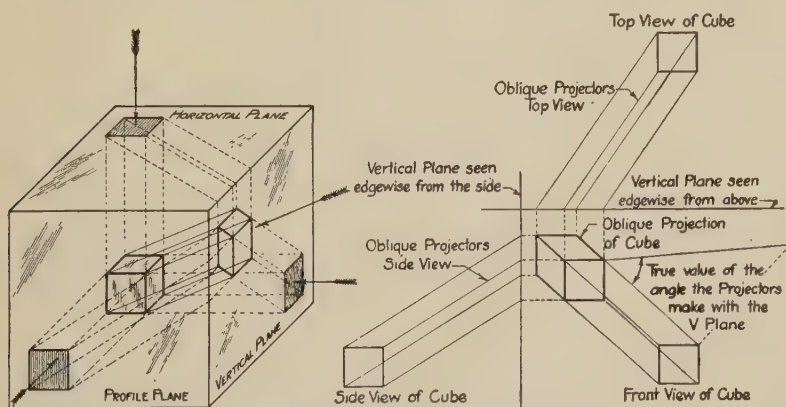


FIG. 2. Construction of an oblique projection.

From the above discussion it follows readily that a horizontal line in space parallel to the plane of projection will project as a horizontal line, and a vertical line will appear vertically on the plane of projection. Figure 2 assists in making these facts clear.

The projection of the three coördinate axes,  $OX$ ,  $OY$ , and  $OZ$ , ordinarily used in Solid Geometry are called the *directrices* or *oblique axes*. It should be observed in Fig. 3 that  $OX$  and  $OY$  are respectively horizontal and vertical and should always be assumed to be so, irrespective of the angle chosen for the receding directrix.

**CAVALIER PROJECTION OF A SOLID.** — Assume a rectangular box with one of its faces in the plane of projection, as in Fig. 2. Obviously, the front face, since it is in the V-plane, projects upon

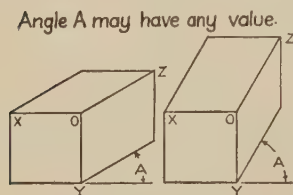


FIG. 3. Two positions of oblique axes.

that plane in its true size and shape. Likewise, the edges which are perpendicular to the plane project in their true length, as do all other lines parallel to them, because the projecting lines make 45 degrees with the plane. Therefore, as in isometric drawing, true measurements can be made along the three directrices or parallel thereto. They can also be

made in any direction in the front face or in any plane parallel to it, since lines in the front face, or in parallel faces, project in their true relation to each other, just as they do in orthographic projection.

To make a cavalier projection of a block, select any point  $O$  as an origin, and draw the two axes  $OY$  and  $OX$  at right angles to each other, the one vertically and the other horizontally as in Fig. 3. The remaining axis  $OZ$  may then be drawn at any convenient angle which will meet the space requirements of the drawing. If the two sides are of chief interest the line  $OZ$  should be made to approach the horizontal, whereas, if the front and top are of chief importance, the axis  $OZ$  should approach the vertical. Since lines which are parallel have their projections parallel, the remainder of the block may be quickly drawn using the same scale for measurements on all axes.

**CAVALIER PROJECTION OF PLANE FIGURES.** — The drawing of plane figures in cavalier projection involves little difficulty, since the scheme of construction is identical with the coördinate method, described fully under Isometric Projection. Figure 4 shows clearly how such figures may be constructed by coördinates.

One of the advantages of cavalier projection is in the fact that the front face of an object is shown without any distortion, as is the case in true orthographic projection. Good judgment, there-



fore, suggests that the face of an object having the greatest number of circles or other curved lines and irregularities in it should be made the front face, unless it is necessary to adopt some fixed point of view, in order to show the object to best advantage, with other faces in the foreground. Figure 5 illustrates this point. It occasionally

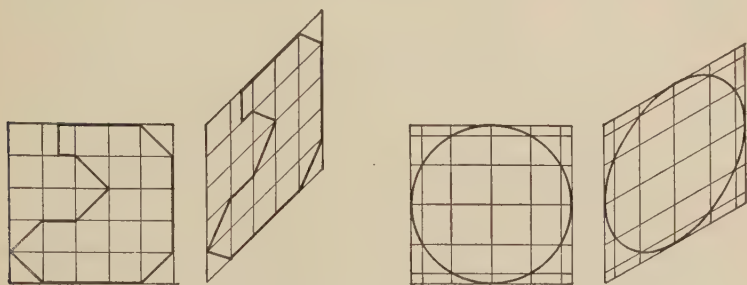


FIG. 4. Oblique projection, coördinate method.

happens, however, that more than one face will contain circles and curved lines. If such is the case, those in receding faces may be constructed by the coördinate method illustrated in Fig. 4.

Circles, however, may be represented by an approximate mechanical method in which arcs of circles are substituted for separate

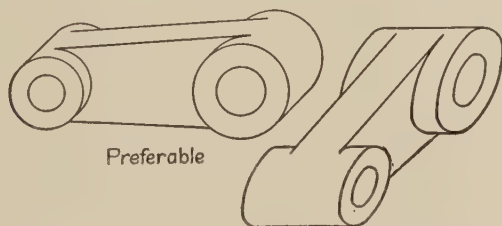


FIG. 5. Choices of position.

portions of the true ellipse, as illustrated in Fig. 6. A circle may always be inclosed in a square; and since it is tangent at the midpoint of the sides of the square, the cavalier projection must show an ellipse which is tangent to the midpoint of the sides of its inclosing parallelogram. Hence, to find the centers of the four arcs, erect perpendiculars to the midpoints of the four sides and find their intersections as shown in the figure. It should be noted that, as the ratio of the major to the minor axis of the ellipse increases, the approximation becomes less accurate.

A cavalier projection frequently has a very disagreeable appearance of distortion or spread in the receding parallel lines, especially if the object is longer than it is wide. This apparent lack of parallelism would be reduced if one always took care to adjust his point of view to a position more suited to the particular drawing he is

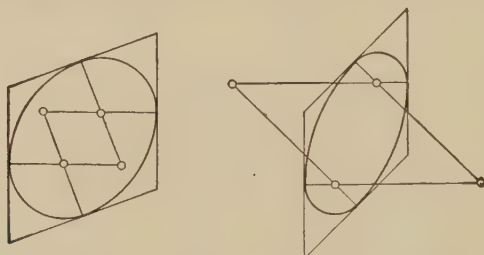


FIG. 6. - Four center method, cavalier projection.

observing than is usually convenient when reading from a textbook page. On objects which have one dimension decidedly shorter than the other two, the apparent distortion may be lessened slightly by making the shorter dimension on the receding directrix. This suggestion cannot be laid down as a fixed rule, however, for the advantage gained may be more than offset by other bad effects pro-

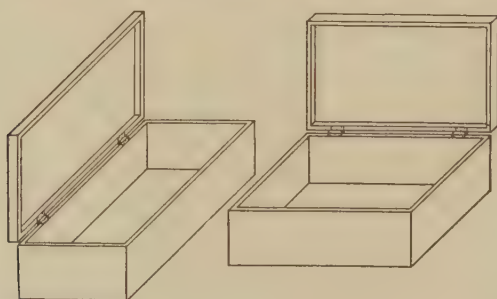


FIG. 7. - Apparent distortion in cavalier projection.

duced, chief among which is that of false expression of the proportionalities of the length, breadth, and thickness of the object.

The ideal in any pictorial drawing is to represent an object as it actually exists or as it appears to the eye. Figure 7 is drawn to scale in cavalier projection to represent a box, the lower part of which is 3'-0" wide, 1'-6" deep, and 5'-0" long. The drawing at the left has the long dimension on the receding axis, while the view

to the right is drawn with the short dimension on the receding axis. The distortion in the first case may be a trifle more noticeable than in the second; but the drawing appears considerably more like a box that is almost twice as long as it is wide than does the second, which seems to portray a box that is almost square in plan with a lid that will not reach all the way across.

Hence, while it is true that making the longer dimension parallel to the plane of projection may reduce the apparent distortion somewhat, it is quite clear that the draftsman must use his judgment in applying any "rule of thumb" in oblique projection.

The first suggestion, however, in regard to making the irregular face the front of the object, always holds, and should take precedence over the second suggestion in regard to distortion, because the elimination of difficulties of construction is usually more important than the elimination of unpleasing appearance.

**CABINET DRAWING.** — A better method to overcome distortion has been developed in a variation of oblique projection called *cabinet* drawing. This variation consists in arbitrarily shortening the dimensions on the receding axis by one-half. Thus, if a scale of  $1'' = 1''$  is used for lines on the front face, a scale of  $\frac{1}{2}'' = 1''$  should be used for lines on the other faces that are parallel to the receding

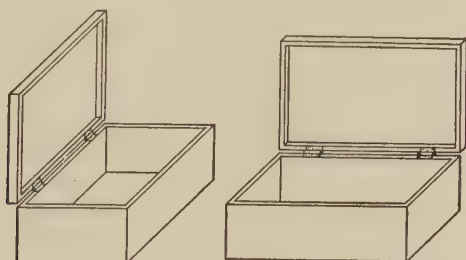


FIG. 8. Reduction of distortion.

directrix. The approximate mechanical method of representing circles, as explained in cavalier projection, cannot be used in cabinet or general oblique drawing.

**GENERAL OBLIQUE DRAWING.** — The dimensions on the receding directrix may, for the sake of appearance and convenience, be foreshortened by some other amount than one-half, as the individual case may require. Thus,  $\frac{3}{8}'' = 1''$ , or  $\frac{5}{8}'' = 1''$ , or  $\frac{3}{4}'' = 1''$  may be found to give excellent results in some cases. For example, the box shown in Fig. 7 has been redrawn in Fig. 8, showing it in

both positions with the dimensions on the receding axis foreshortened by one-third. The appearance in either case is quite pleasing to the eye. In this example, both views can easily be imagined to represent the same box.

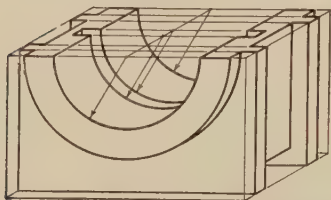


FIG. 9. Construction planes, oblique projection.

This scheme, in effect, is simply that of using some other angle than 45 degrees for the projecting lines, which, of course, puts the drawing itself into the class of general oblique drawing.

As in isometric, the construction of objects naturally falls into a series of parallel oblique planes, and care should be exercised to make constructions in the proper plane. Figures 9 and 10 illustrate the general scheme.

*The coordinates a-1, b-2, b-3, c-4, etc are the same for each arm. The construction indicated gives a rapid method of solution.*

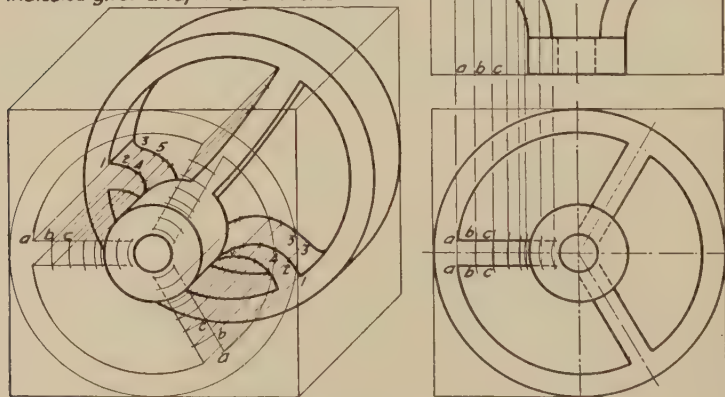
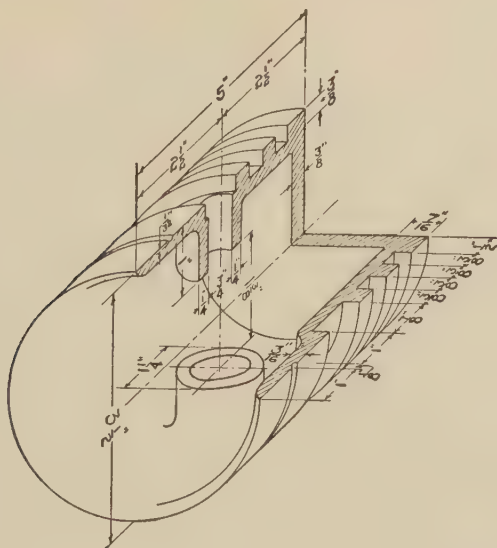


FIG. 10. Box construction in oblique projection.

**DIMENSIONING.** — The rules for dimensioning oblique drawings are the same as for isometric drawing. It should be emphasized that both these pictorial drawings are one-view representations; and the only safe rule for dimensioning is to make all figures read from one point of view, instead of from two sides of the drawing sheet, as is done in orthographic projection. Care should be taken also to have the dimensions placed in oblique planes. This can be done by keeping the axes of numerals and letters parallel to the cor-

responding directrices. Figure 11 illustrates good practice in this regard.







## CHAPTER XII

### VARIATIONS OF OBLIQUE PROJECTION

#### SECTION 2

In the first section of this chapter, the object to be drawn was always placed with one face parallel to the plane of projection; this is an essential element in oblique projection, as there discussed. While the advantages to be obtained by this means are of considerable practical importance in the way of convenience and speed, it must be borne in mind that oblique projections of an object can be made regardless of its position relative to the plane. The essential fundamental concept in oblique projection lies in the fact that the projecting lines are parallel to each other and oblique to the plane

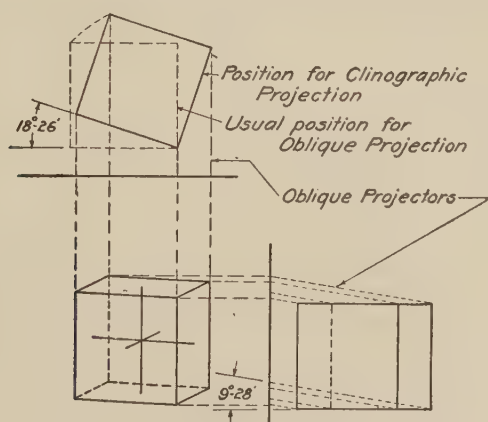


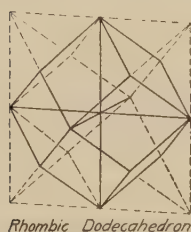
FIG. 1. — Clinographic projection of cube.

of projection. The position of the object relative to the plane may or may not facilitate the work of construction, but this does not change the method of projection.

For some purposes it may be desirable to turn the object at an angle to the plane of projection, particularly if there are no curved edges in its outlines. In fact, just such a system of oblique pro-

jection, called clinographic projection, has become firmly established in the field of mineralogy and crystallography, in representing the various mineral crystals.

In clinographic projection, the angles which the three principal axes of the crystal make with the plane of projection, and the angle which the projecting lines make with the plane, have become fixed by usage, although there is no inherent reason why other angles might not have been used just as effectively.



*Rhombic Dodecahedron*

FIG. 2. Crystal in clinographic projection.

These angles are shown in Fig. 1, in the clinographic projection of a cube. For construction purposes, it is well to remember that the tangent of  $18^\circ 26'$  is  $\frac{1}{3}$ , and the tangent of  $9^\circ 28'$  is  $\frac{1}{6}$ . From an observation of the figure, it is clear that the vertical line projects in true length, while the others are foreshortened, each by a different amount. In clinographic projection these foreshortened scales are determined accurately; approximations of scales or arbitrary assumptions are not permitted. In practice, the three coördinate axes shown inside of the cube are used as the skeleton upon which the crystal is drawn as illustrated in Fig. 2.

Three of the six principal systems of crystals have their three axes of varying lengths and at right angles to each other. The

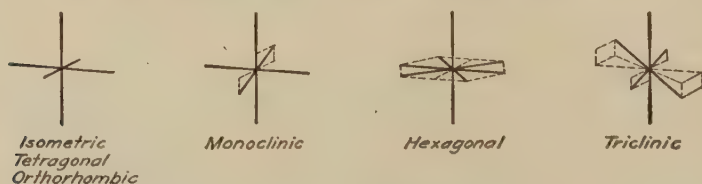


FIG. 3. Axes in six crystal systems.

other three systems have axes which make angles with each other, differing from 90 degrees as shown in Fig. 3. All six sets of axes are drawn upon the cubic axes as a basis.

Clinographic projection is strictly an oblique projection, and although three different scales are used upon the axes, it is not for this reason to be called a trimetric projection, any more than we should call a cavalier projection an isometric projection, for the

same reason. So far as appearance and actual construction are concerned, however, oblique projections can be made to appear quite similar to dimetric and trimetric projections, as is quite evident from a comparison of the clinographic projection of the cube in Fig. 1 and the dimetric of the cube in Fig. 3 of Section 2, Chapter XI.

Further information concerning clinographic projection may be found in the texts listed below.

DANA'S TEXTBOOK OF MINERALOGY. Appendix A. By W. E. Ford. John Wiley & Sons, Inc., New York, 1922.

CRYSTALLOGRAPHY AND PRACTICAL CRYSTAL MEASUREMENT. Chapt. XXV. By A. E. H. Tutton. Macmillan and Co., New York, 1911.

## CHAPTER XIII

### PERSPECTIVE

The following discussion of the principles of perspective projection and their application to simple problems should be considered by the student of this kind of projection as the mere foundation of a further study of the whole subject. Only fundamental conceptions are here set forth. Some authors have found it necessary to use two volumes of concisely written exposition in order to present properly the various phases of perspective drawing. Each object presents new problems peculiar to itself. Shading and rendering, multiple vanishing points, short cuts in construction, etc., are some of the points to be developed in more extended discussions than this chapter is planned to give. To those interested in perfecting themselves further in the technics of this fascinating subject, the texts listed at the end of this chapter are recommended.

**DEFINITION.** — A perspective drawing of an object is a representation of that object upon a plane, as it (the object) would appear to the eye from some one definite point of view. Perspectives are sometimes called *scenographic projections*. These projections are very useful when accompanying working drawings for explanatory purposes, or when drawn by the architect or engineer to convey to others definite ideas of form as it is desired in the finished structure that has been conceived and designed. Figure 3, Chapter XIX, very well illustrates the appeal that a perspective may make to the observer — an appeal that is quite impossible with other forms of projection. A single drawing showing the combined plan and perspective gives information of a character hard to excel in any other way. On account of the very close resemblance of the drawing to the object itself as it exists in nature, we find perspective drawing much resorted to by those who wish to produce a pleasing and correct effect upon the observer.

While a perspective drawing, when viewed from any angle, gives a general idea of the object, there is only one point from which it can be viewed to obtain the true proportions of the object repre-



sented. This point must bear the same relation to the drawing, when the scale of the drawing is taken into account, as the real point of sight in space does to the object itself.

**POINT OF SIGHT.** — In all the kinds of drawings studied heretofore, the point of sight has been at an infinite distance from the object, and, as a consequence, the lines of sight, or projecting lines as they are called, have always been parallel to each other. In perspective drawing, however, the point of sight is definitely located at a finite distance from the object. Hence, the lines of sight, or visual rays as they are often called in perspective drawing, will be divergent from the point of sight and will make different angles with the plane of projection.

In fixing upon the exact location of the point of sight in reference to the object, it is customary to keep within the limits ordinarily assumed by an observer in examining the object in its natural environment. Usually this will be a little above and to the right or left of the center of all small objects.

The limits within which the foregoing suggestion holds will depend largely upon the nature of the object and the purpose for which the perspective is to be used. If the top of the object contains features which must be shown, the point of sight must be above the top, regardless of whether this is the usual position or not. Whether the point of sight is in front of the center of the object or to the left or right will also depend upon what one wishes to show of the sides.

For large structures, like buildings and dams, the point of sight should be chosen to best depict the beauty or utility of the structure. A common rule, in the case of buildings of moderate size, is that the distance between the eye and the nearest line on the building should be twice the longest dimension. In the case of a dam, the point of view might be assumed to be as much as a mile away from the actual site.

The suggestions in the preceding paragraphs do not take into consideration the actual appearance of the finished drawing, for the location of the point of sight alone will not determine this. The position of the picture plane must also be considered.

In examining a drawing or photograph, it is customary, particularly if it be of a size to be held in the hand, to hold the picture directly in front of the observer, thus making the line from the eye to the center of the paper almost perpendicular to the paper. This being the case, the picture plane and point of sight should be so lo-



to show a group of buildings or some proposed development plan by making a so-called bird's-eye view. In this case the picture plane is chosen as a horizontal plane.

**PERSPECTIVE OF A POINT.** — From Fig. 1 it is evident that to find the perspective of an object it is only necessary to locate the piercing points of the visual rays, drawn from the eye to the various points on the object, with the picture plane. Figure 2 shows pictorially a point  $A$  in the second angle and a point of sight  $S$  in the first angle a distance  $x$  to the right of  $A$ , a distance  $y$  above  $A$ , and a distance  $z$  in front of  $A$ . It will be noted that this arrangement corresponds to that of Fig. 1 when the corner of the box at  $A$  is considered as the point  $A$  of Fig. 2. The method of laying out the distances  $x$ ,  $y$ , and  $z$  are indicated in Fig. 1 but omitted in Fig. 2.

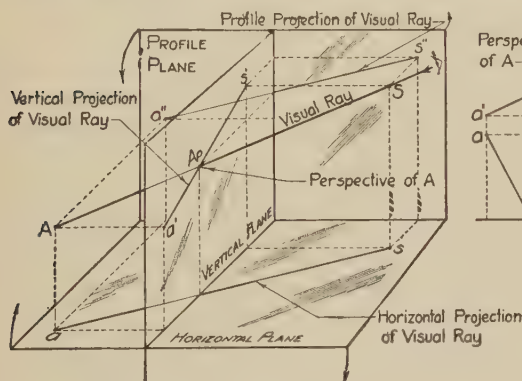


FIG. 2. Perspective of a point, (pictorial).

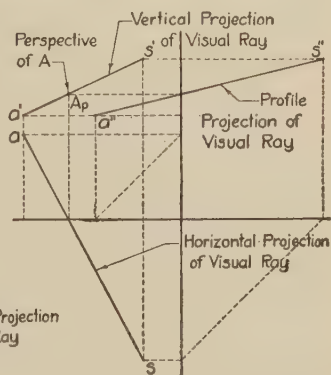


FIG. 3. Perspective of a point, (orthographic).

The orthographic projections of  $S$ ,  $A$ , and the line of sight are shown on the horizontal plane and on the picture plane. The line of sight from  $S$  to  $A$  pierces the picture plane at  $Ap$ ; and  $Ap$ , therefore, is the perspective of  $A$ . That is,  $Ap$  is the representation of  $A$  in the picture plane just as it would appear to the eye from  $S$ .

It should be noted that  $Ap$  is on  $s'a'$ , which is the vertical projection or elevation of the line  $SA$ . It should be observed further that  $Ap$  is directly above the point where  $sa$ , which is the horizontal projection or plan of the line  $SA$ , crosses the ground line. Figure 3 shows orthographically the projections which lie in the horizontal and vertical planes in Fig. 2, and also the projections on the end or profile plane.

Two projections of a point, line, or object are always necessary

to determine completely its position in reference to the principal planes. Therefore, if we have given or can find any two views of a point taken at random in space or located on an object, such as might be shown in any shop drawing, a perspective of the point can be obtained by applying the simple rules given below:

(1) If a perpendicular is erected from the point at which the horizontal projection of a visual ray to the given point crosses the ground line, to the vertical projection of this same ray, the perspective ( $Ap$ ) of the point is located; or (2) if a perpendicular to the profile ground line is drawn from the point where the profile projection of the visual ray crosses the profile ground line, to the vertical projection of the ray, the same point  $Ap$  is located; or (3) if both perpendiculars are drawn, the vertical projection of the ray may be dispensed with altogether and the point  $Ap$  located just as well.

This last rule is true because the horizontal projection of the line of sight gives the location of  $Ap$  in a horizontal direction, and the profile projection gives the location in a vertical direction just as does the vertical projection.

**VANISHING POINTS.** — It is a matter of common observation that long, straight, horizontal, parallel, lines seem to converge as they recede, and finally appear to come together in the distance at a point in the horizon. If, therefore, a line is drawn through the point of sight parallel to any one of a group of parallel lines, let us say the horizontal ones on a building, it will seem to meet not only one but all of them at an infinite distance away and in the horizon. This fact is sometimes expressed in geometry by the statement that "parallel lines meet at infinity." Hence, the point where this parallel line through the point of sight pierces the picture plane is the perspective of the apparent meeting or vanishing point of all the parallel lines. The perspective of the apparent vanishing point is itself universally called the vanishing point of this particular group of lines. Since only one line can be drawn through the point of sight parallel to any group of parallel lines, such a group can have only one vanishing point. Each separate system of parallel lines, however, will have its own vanishing point. Figure 4 shows the method of finding vanishing points pictorially, and Fig. 5 shows the same thing orthographically. It is well to remember in this connection that *parallel lines in space have their projections parallel on the same coördinate plane.*

Two horizontal lines,  $AB$  and  $BC$ , are shown in the second quad-



rant with a point of sight,  $S$  in the first quadrant. In Fig. 4, a line is drawn through  $S$ , parallel to  $AB$ . Where this line pierces the picture plane at  $v'$  is the vanishing point for  $AB$  and all lines parallel to it. In the same way, the vanishing point  $v_1'$  is found for  $BC$  and lines parallel thereto.

In Fig. 5 the same procedure is carried out after the horizontal plane has been revolved into the picture plane, as is shown pictorially in Fig. 4. Through  $s$  draw a line parallel to  $ab$  until it

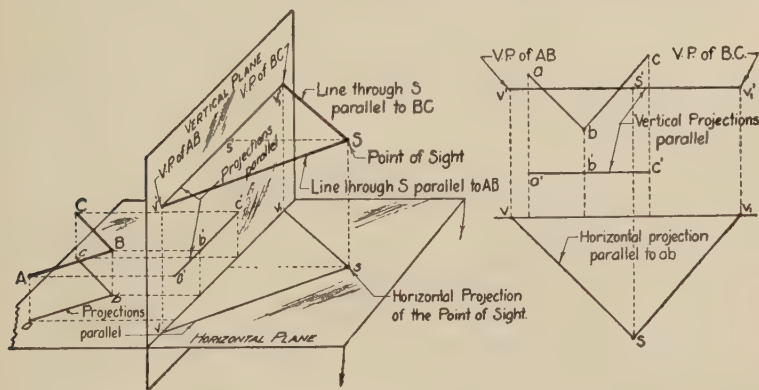


FIG. 4. Vanishing points of horizontal lines, (pictorial). FIG. 5. Vanishing points of horizontal lines, (orthographic).

crosses the line representing the picture plane. Here erect a perpendicular and extend it until it intersects a line drawn through  $s'$  parallel to  $a'b'$ . This is the vanishing point for  $AB$ . The vanishing point for  $BC$  may be found in the same manner. It will be noted that both these vanishing points lie in the horizontal line passing through  $s'$ . This line is called the *horizon*, and it will contain the vanishing points of all sets of parallel horizontal lines. We may visualize this fact the better by recalling that lines on the earth's surface which are horizontal and parallel, such as the two rails of a track, seem to vanish in nature's horizon. The line of sight from the eye will also be parallel to the tracks in the above case, and will also vanish with them in the same point in the horizon. On the drawing paper, the horizon is the intersection of the picture plane with a horizontal plane passed through the point of sight. If this horizontal plane is extended it will seem to contain nature's horizon also; hence the real reason for the term horizon as used in perspective drawing.



### VANISHING POINTS FOR OTHER THAN HORIZONTAL LINES. —

The draftsman must not conclude that, since horizontal lines all have their vanishing points in the horizon, regardless of their direction, the same thing is true for lines not parallel to the horizontal plane. However, the principles for finding the vanishing points of horizontal lines, which were fully explained in the preceding paragraphs, still hold good for oblique lines. These principles may be briefly summarized in rule form as follows:

*Through the point of sight, draw a line parallel to the lines whose vanishing point is desired, and find where this line pierces the picture plane. This piercing point is called the vanishing point of the group of parallel lines.*

The rule as stated above applies to the conditions as they exist in space; hence, to apply the rule on paper it must be remembered

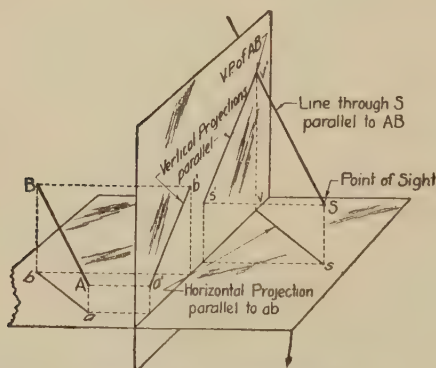


FIG. 6. Vanishing point, oblique lines, (pictorial).

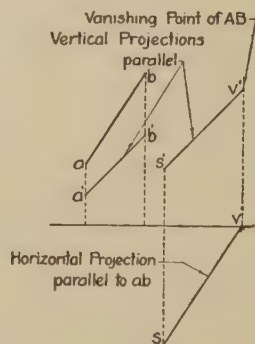


FIG. 7. Vanishing point, oblique lines, (orthographic).

that two projections of the point of sight and two projections of each line are absolutely necessary to fully represent them, and further that two projections of the line drawn through the point of sight must also be shown. Figure 6 illustrates the case pictorially, and Fig. 7 represents the same thing orthographically — as the draftsman would represent it. The horizon is not shown in either of these figures, but it would pass horizontally through  $s'$ , if it were drawn.

The vanishing point of all lines perpendicular to the picture plane is the vertical projection of the point of sight.

Lines perpendicular to the horizontal plane or parallel to the picture plane have no vanishing point.

**PERSPECTIVE OF A SOLID.** — Since the perspective of a solid object consists simply of the perspective of its outlining or definitive points and edges, such a perspective may be constructed by simple repetition of the procedure described above, which is known as the *visual ray method*, and which is further elaborated below under two main divisions. A problem may be stated as follows: — Find the perspective of a cube in the third quadrant, 1 inch on the edge, having one face parallel to the picture plane and 1 inch behind it. The point of sight is to be 4 inches in front of the cube, 2 inches to the right of it, and 2 inches above it. The location of the point of sight might also be expressed in terms of the usual three coördinate distances,  $x$ ,  $y$ , and  $z$ . Thus  $+x$  would indicate the distance to the right and  $-x$  the distance to the left;  $+y$  would indicate the distance above and  $-y$  the distance below; and  $z$  the distance in front of the point of reference on the object.

**Parallel or One-point Perspective.** — It is first necessary to draw the horizontal and profile projections of the cube and point of sight,

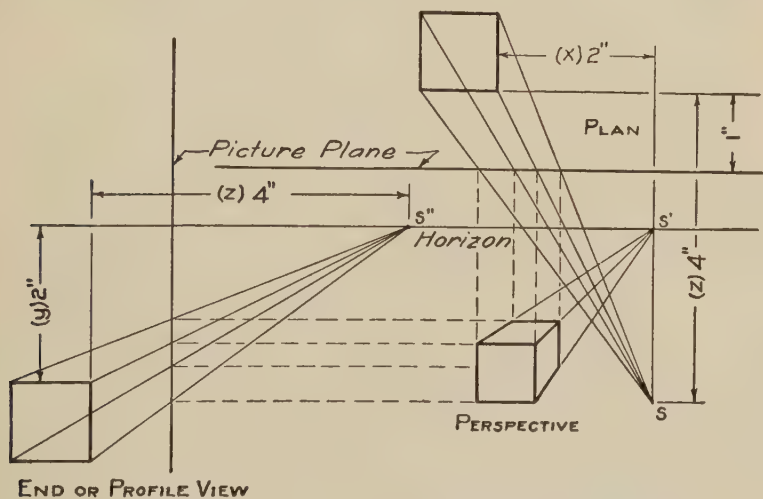


FIG. 8. Parallel perspective by visual ray method.

showing them in their true relation to each other and to the picture plane (vertical plane), as specified in the problem. These are shown in Fig. 8, in the customary third and fourth-angle projection. The vertical projection is omitted, because it is not necessary to the construction, and it would quite seriously interfere with the finished perspective. The perspective of the eight corners of the cube may

now be located in the same manner as the single point  $A_p$  in Fig. 2. If these points are then connected in the proper order, the perspective of the cube is complete. Evidently the edges of the cube which are perpendicular to the picture plane will vanish at  $s'$ . The other lines do not have vanishing points.

Since the object in Fig. 8 is placed with one of its principal faces parallel to the picture plane, thereby leaving only one set of parallel lines which can have a vanishing point, this type of perspective is called *parallel, or one-point, perspective*.

**Angular or Two-point Perspective.** — Suppose the cube to be placed in the position shown in Fig. 9. The vertical faces make angles of 30 degrees and 60 degrees, respectively, with the picture

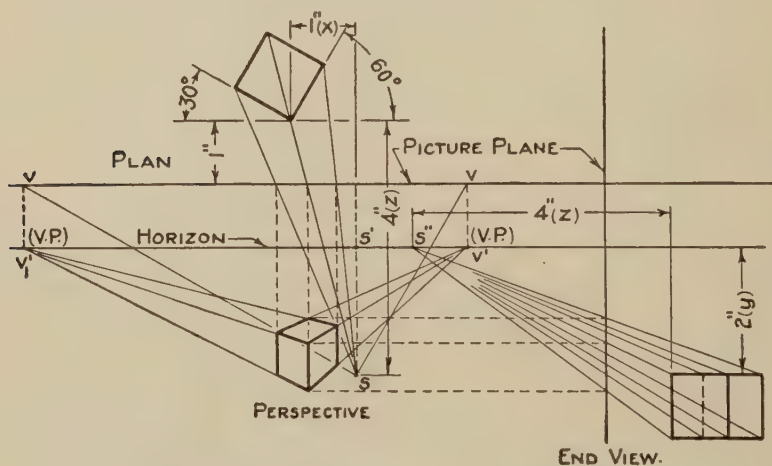


FIG. 9. Angular perspective by visual ray method.

plane, and the front edge is 1 inch behind it. The point of sight is 2 inches above the top face, 4 inches in front of, and 1 inch to the right of the front edge. The construction of the perspective may be completed as before, by finding the perspectives of the eight corners. In this case, it will be noted that there are two vanishing points, both in the horizon. This type of perspective is therefore called *angular, or two-point, perspective*. It will be noted that the profile or end view has been turned in the opposite direction from that in Fig. 8. The various steps in the construction of the perspective are shown in the figure.

The perspective of so simple an object as a cube may be readily found by the *visual ray method* described above, and illustrated in

Figs. 8 and 9; but for more complicated problems this method would be very cumbersome. It would seriously limit the use of perspective, since the point of sight would always have to be located on the drawing board. In addition, a complicated profile view would frequently have to be constructed, particularly in angular perspective. The *line method*, so called, will be found more suitable in most instances.

**Line Method.** — In order to simplify the process of construction, the perspective of a line may be used as the foundation of the work, instead of the perspective of the point as in the above schemes. The perspective of a line may be found by finding the perspective of any two of its points. One of these points may be the vanishing point and the other the point where the line extended pierces the picture plane. The latter point is its own perspective. By drawing from this point to the vanishing point the perspective of the line is found.

In Fig. 10 for example, the perspective of one point of the line  $AB$  may be found by extending it until it pierces the picture plane

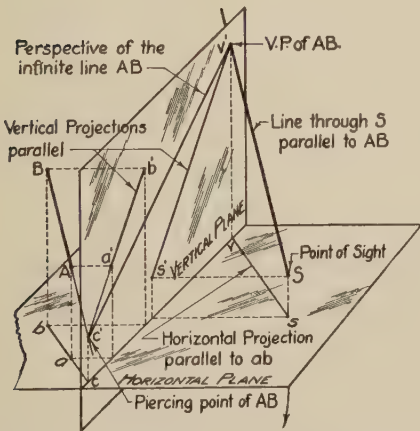


FIG. 10. Perspective of a line by two points in it (pictorial).

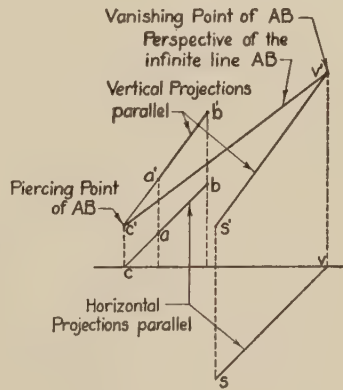


FIG. 11. Perspective of a line by two points in it (orthographic).

at  $c'$ . The vanishing point for  $AB$  and all lines parallel to it may be found in the usual manner. Then by connecting  $c'$  with the vanishing point  $v'$ , the perspective of the unlimited line, of which  $AB$  is a segment, is found. In Fig. 11, this procedure is carried out orthographically. The vanishing point is found by first drawing a line through  $s$  parallel to  $ab$  and through  $s'$  parallel to  $a'b'$ .

Where the line through  $s$  crosses the ground line, which is the intersection of the picture plane with the horizontal plane, erect a perpendicular until it crosses the line through  $s'$ . This intersection is the vanishing point  $v'$ . To find  $c'$  extend  $ab$  until it crosses the ground line, and there erect a perpendicular until it crosses  $a'b'$  produced. Then  $c'v'$  is the perspective of the unlimited line indicated by  $AB$ . How to find the perspective of the limited portion  $AB$  is clearly brought out in Fig. 12 and the following discussion pertaining thereto.

To find the perspective of an object by the method just described, it is first necessary to draw the plan of the object and point of sight in their proper relation to the picture plane. The plan of the object should be placed well toward the top of the sheet, or it may be made on a separate sheet and placed above the sheet on which the perspective is to be made. Next, the horizon is drawn in such a position that the finished perspective will have the desired location

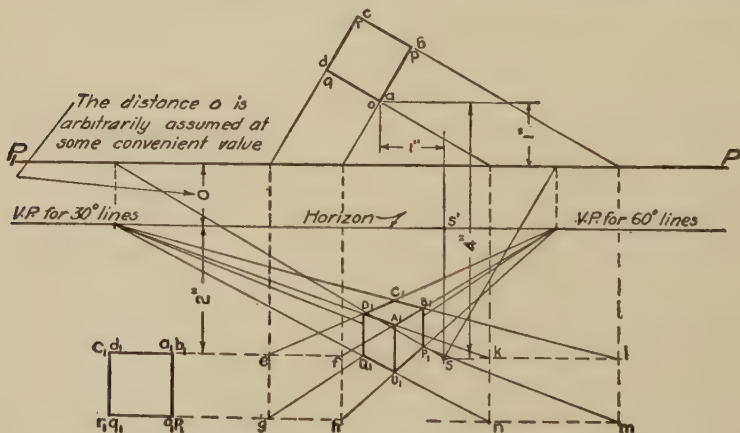


FIG. 12. Angular perspective by line method.

on the sheet. An elevation of the object may then be drawn at the left end of the sheet, in proper relation to the horizon, but without reference to the plan view, as it is used only to determine the vertical dimension of the perspective. This relation is easily established when we remember that the horizon is simply the intersection of a horizontal plane, through the point of sight, with the picture plane. Both the plan and elevation views of the point of sight should, of course, be shown in their proper relation to each other and to the views of the object.



As an example of this method, assume a cube as in Fig. 12, having the same dimensions and relations to the picture plane as in the problem in Fig. 9. Locate the vanishing point for  $AB$  and lines parallel to it, by drawing through  $s$  a line parallel to  $ab$  until it crosses  $P_1P$ . Then drop a perpendicular from this point on  $P_1P$  to the line through  $s'$  parallel to the vertical projection of  $AB$ , which line, of course, coincides with the horizon. The intersection is the vanishing point for the 60 degree lines. Likewise, find the vanishing point for  $AD$  and other 30 degree lines. In one or the other of these two vanishing points, we now have a point in the perspective of every line in the cube except the vertical lines. If the horizontal edges of the cube be extended to meet the picture plane, another point in each line may be found as in Fig. 11. Produce  $ab$  and  $ad$  until they intersect  $P_1P$ . Then drop perpendiculars from these intersections until they cross lines projected horizontally in from the elevation of the cube at the left. These projecting lines are, of course, the same distance below the horizon as the lines  $AB$  and  $AD$  are below the point of sight. This locates the piercing points  $f$  and  $k$ . Connecting  $f$  and  $k$  with the proper vanishing point gives the perspectives of the lines  $AB$  and  $AD$  extended. The intersection of these two perspective lines at  $A_1$  gives the perspective of the front corner of the cube. Other lines and corners may be determined in the same way, and the whole perspective of the cube completed.

A casual comparison of Figs. 9 and 12 is sufficient to show the advantages of the line method over the visual-ray method, on even as simple an object as a cube. On more complicated objects, still greater economies of time and space are effected.

**MEASUREMENTS IN PERSPECTIVE.** — Since the cube in Fig. 12 is 1 inch on the edge, the distances  $eg$ ,  $fh$ ,  $kn$  and  $lm$  will be 1 inch, but not a single line in the perspective of the cube itself will be 1 inch long. Measurements can be made to scale in perspective work in the location of the projections of the object and point of sight, in the coördinate planes, and in a vertical direction on the picture plane in constructing the perspective by the *line* method. No scale measurements may be made on the perspective itself, unless, perchance, one of the lines or faces of the object is placed in the picture plane, whereupon the elevation of all such lines becomes the perspective. Distances are obtained, in general, by intersecting lines, as in Fig. 12.

It will be observed that the only use made of the point of sight

in the line method is to locate the vanishing points. See Fig. 12. The vanishing points are, of course, dependent upon the distance of the point of sight from the object, and are sometimes referred to as *distance points*. If it is not necessary to have the point of sight in some very definite position, the vanishing points may be assumed at will, and the location of the point of sight allowed to come as it may. An experienced draftsman, by locating his plan relative to the chosen vanishing points, can make the point of sight very close to any specified location.

**GENERAL METHODS.** — In Fig. 13, the construction of geometric plane figures in perspective is shown. Briefly, the method

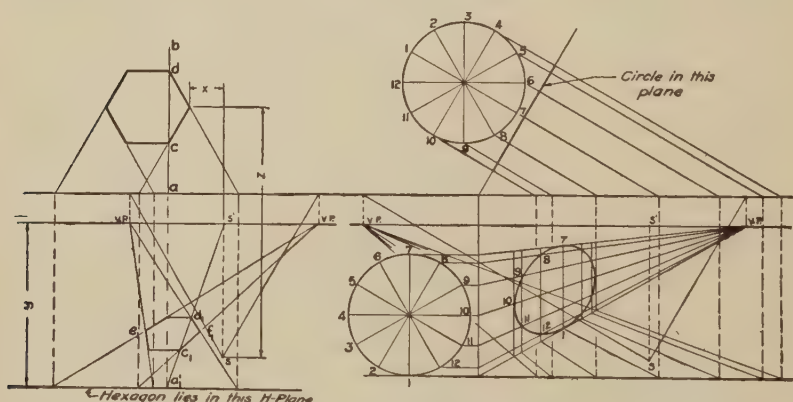


FIG. 13. Perspectives of plane figures.

consists of drawing two lines through the point whose perspective is desired, and then finding the intersection of these two lines in perspective. Naturally, one would choose lines whose perspectives are easily found.

The hexagon is shown lying in a horizontal plane, a distance  $y$  below the point of sight. The vanishing and piercing points for both sets of 60-degree lines are found in the usual manner. Their perspectives are then drawn. Only the intersections  $e_1'$  and  $f_1'$  of these four lines locate corners on the hexagon. The remaining corners may be found by drawing a line, such as  $AB$ , through the corners  $C$  and  $D$ , and locating its perspective. The intersection of this perspective  $s'a'$  with the perspectives of the 60-degree lines locates the corners  $c_1'$  and  $d_1'$ .

The circle is shown in a vertical plane which is inclined to the

picture plane. The perspective of the circle may be found by locating the perspectives of twelve or more points on it, and then drawing a smooth curve through the points thus found with an irregular curve. The perspectives of the twelve points may be found by drawing through them a series of coördinate lines, vertically and horizontally. The perspectives of these coördinate lines can be readily found in the usual manner. It will be noted that the circle just to the left of the perspective is used only for vertical dimensions, which are transferred to the right, to the line where the horizontal coördinate lines pierce the picture plane.

Familiarity with the theory of perspective, which comes from practice, will enable the draftsman to discover many short cuts for himself, which will save not only time but considerable labor as well.

#### BIBLIOGRAPHY

- MODERN PERSPECTIVE, by Wm. Robert Ware. The Macmillan Co., New York, 1900.
- PERSPECTIVE SKETCHING, by Frank Elliot Mathewson. The Taylor-Holden Company, Springfield, Mass., 1918.
- PERSPECTIVE DELINEATION, by Boyd A. Gill. Architectural Book Publishing Company, New York, 1921.
- PERSPECTIVE, by Ren. Vicat Cole. J. B. Lippincott Company, Philadelphia, 1921.
- APPLIED PERSPECTIVE, by Wm. P. P. Longfellow. Houghton Mifflin Company, New York.

## CHAPTER XIV

### SKETCHING

However expert and proficient the engineer may have become in presenting his designs to others in the graphical language through the use of drawing instruments, he cannot hope to attain full success in the use of this language, and hence, in his profession, until he has mastered tolerably well the art of sketching, in the technical sense. By the term sketching, as here used, is meant the representation, by means of *freehand drawings*, of objects with which the engineer has to deal. Any one of the four major projections hitherto discussed in this text may be used. These freehand drawings, or sketches, are not to be thought of as the pen or pencil sketches of the artist or architect. They have nothing to do with the art of painting on canvas. They are simply freehand orthographic, isometric, oblique, or perspective drawings of machines or parts of machines, buildings, and other structures with which the engineer has to do. They may or may not be dimensioned, depending upon the use to be made of them. In every important way, they conform to the conventional standards of mechanically made drawings. For the sake of better explanation and distinction they are sometimes called technical sketches.

The purposes of technical sketches are, (1) to transmit information obtained in the field to the drafting office, (2) to form a medium through which one engineer or draftsman may transmit a true understanding of his designs and plans to another person, thus forming a basis for discussion, and (3) to serve as a means for working out preliminary designs incident to the actual preparation of working drawings. It is, therefore, necessary that most sketches be made in orthographic projection, with as many views and sections as are necessary for the correct and complete recording of all the information to be transmitted by the sketches.

It may be helpful to the student, in his attempt to grasp the full importance of sketch work, to call attention to the fact that the major portion of all the designs made by the designing engineer of any company are first prepared in the form of freehand or rough

instrumental sketches, which are turned over to the detailer or draftsman, who then draws them to scale, thus making them ready for the shops. Such sketches are usually made on the sheets used in computing the sizes of the parts required to carry the loads specified, or on separate sheets which are bound with the computations. It is helpful to know, further, that sketches are indispensable when measurements are being taken on repair work, where it is not only necessary to secure dimensions of the broken part, but often information concerning surrounding parts needs to be obtained. Suggested improvements, extensions, and revisions of existing equipment and structures also require the engineer to exercise his ability at sketching.

Isometric and other pictorial sketches are useful for conveying ideas of form or shape, but can hardly serve for purposes of dimensioning when the object represented is more or less complicated. As auxiliary to orthographic sketches, although drawn to a much smaller scale, they serve a very useful purpose and should be freely used in this way.

For the beginner in technical sketching, there are two important elementary points to be mastered before the physical work involved can be done with ease and speed. The first element entering into successful sketching is the freehand stroke of the pencil. The second element is that of correct proportion and size. Each of these elementary factors in good sketching is discussed hereafter.

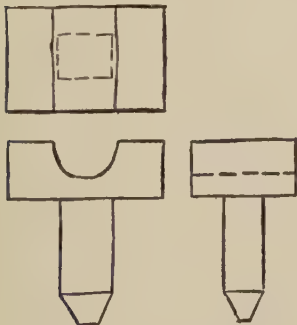


FIG. 1. Rough sketch.

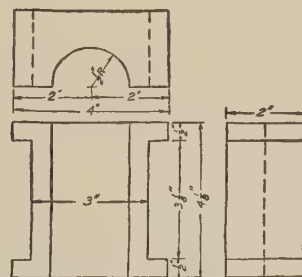


FIG. 2. Dimensioned sketch.

**SKETCH STROKE.** — A freehand line should be made up of a series of short, sketchy strokes of the pencil, each succeeding stroke lapping back a short distance over the preceding one. By means of this overlapping of strokes and short extension process, one



may produce a line indefinitely, and at the same time keep it fairly straight, though somewhat rough. The element of roughness may be removed, if desirable, after the sketch is proportioned satisfactorily, by erasing and retracing the lines more carefully. The complexity of the sketch and one's judgment are the only guides in determining how roughly a sketch may be executed.

The direction of stroke should be from left to right for all lines of not more than 45-degree slope to the horizontal, in either direction. For other lines, the stroke may be either up or down the drawing sheet. Figure 1 shows the character of the sketch line accepted for purposes of indicating the shape of an object only, such as would be used if one engineer were explaining his designs to another. If dimensions are to be given, the sketch stroke should be as smooth as that shown in Fig. 2.

**PROPORTIONING.** — Since measurements are seldom taken on the object while the sketch proper is being made, it is important that a keen sense of relative proportions be developed by the draftsman or engineer. It is not so necessary in sketch work that one be able to estimate closely the *actual* dimensions of any object, but one must be able to judge the *relative* lengths of the various lines to be represented. That is, one must first estimate carefully the relation between the overall lengths, widths, and heights on the object, and block out spaces on the sketch sheet for each view, with close approximation to the relations existing among the corresponding sizes on the object. After the main outlines have been satisfactorily proportioned, some of the more important features should be located, such as the center lines of holes, bosses, shafts, pulleys, whereupon the lines representing these things should be sketched in. After this has been done, the small details may be put in and the dimensions added. Figure 3 shows these three stages in the execution of a sketch for a gas-engine piston. After the outlines have been gone over and smoothed out and poorly placed dimensions changed, general notes should be put in, including, of course, the name of the sketcher, the date, and the name of the object sketched. Contrast between lines should be kept as much as possible like that used on working drawings, and to this end one should go over the outlines a second time and bring them out clearly from the other lines.

**SKETCH MATERIALS.** — Most draftsmen find 2H, 3H, or 4H pencils best suited to sketch work. It is well to have all three available. The 3H is soft enough to make erasing very easy; yet it is

not so soft that frequent sharpening is necessary; neither does it give a very black, charcoal effect to the sketches. The 2H may be used for bringing out important outlines and the 4H for putting on dimensions and notes when the space for them is limited, otherwise the 3H may be used.

The paper to be used will, of course, depend upon the circumstances under which the sketch is made. Generally speaking,

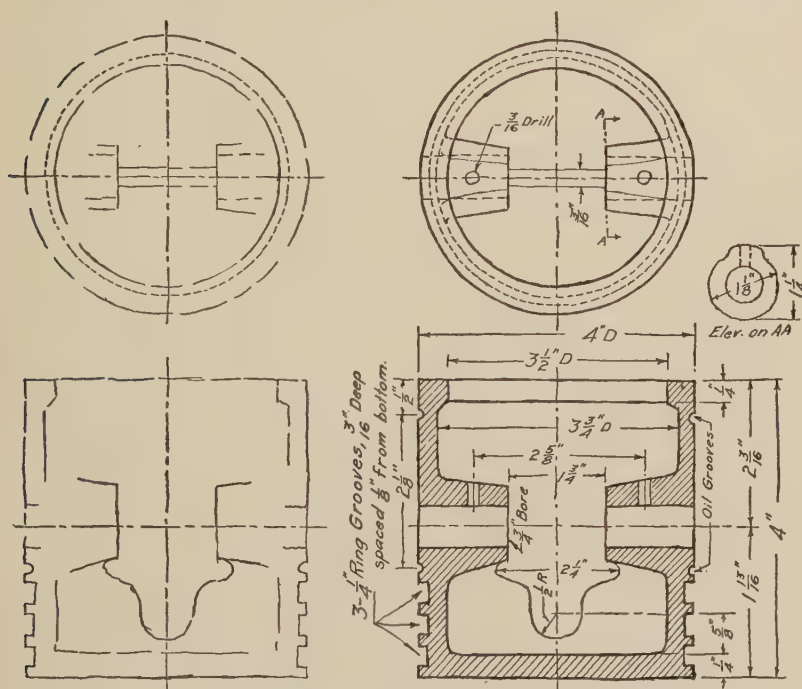


FIG. 3. Progressive sketching.

drafting offices carry regular sketch pads or books in which the sheets are ruled with horizontal and vertical lines, and in some cases with isometric lines, to facilitate proportioning and to assist the sketcher in keeping his lines straight and parallel. Any paper may be used, however; but sketches done on anything at hand are often lost, and new ones have to be secured.

Other essential pieces of equipment are an eraser, steel scale, calipers, cloth or steel tape, and a small triangle. The last three are for the purpose of securing the dimensions of the object.

**DIMENSIONING A SKETCH.** — After all of the detail has been drawn in on the various views, the dimensions must be secured from the object and added to the sketches. Often a sketch is made in the field, where access to the measuring devices of the shop are not possible. Recourse to measuring schemes of all kinds must be had, in order that no important dimension is left off the sketch. The rule in sketching is to get all the dimensions, and get them right, while the sketcher is on the job the first time. Extra trips are costly in time and money.

After all the measurements thought necessary have been taken from the object, the dimensions on the sketch should be checked up by the processes of addition and subtraction, to see that no error has crept in through mismeasurement or otherwise. All additive overall dimensions should be rechecked against actual measurements, if this was not done in the first instance.

Again, the sketcher must exercise good judgment in choosing the dimensions that will be needed in the drafting room and in deciding upon the relative degrees of accuracy with which various measurements are to be taken. In places where every part of the machine or object being sketched is machined, care must be taken to secure dimensions accurate to within the customary allowances and limits used on such work. On rough and poorly designed castings, less accurate measuring is permissible. Cases will even arise in which the sketcher should change dimensions to correct obvious mistakes in fit or design. For instance, it is not unusual to find castings, supposedly symmetrical about a plane or axis, with the dimensions on one side of the axis seriously disagreeing with those on the other side. The sketcher should note this discrepancy and decide, in the field, which dimensions are right.

Too much emphasis cannot be put upon the necessity of discriminating between dimensions that are useful and required, and those that are of little value or wholly useless. It is very easy to cover a drawing completely with dimensions which no one will ever use and which, in some cases, cannot be used. Such, for instance, are radii of slightly rounded corners and intersection curves due to machining processes, curves caused by insertion of bosses, interior dimensions which cannot be connected with outside dimensions, and others of like character.

Dimensions may be put on a sketch in violation of every rule of dimensioning prevailing in the drafting room, so long as each one is clear and unmistakable in its meaning. Nevertheless, it will be

found advisable to adhere closely to the regular rules, except where substitutes can be made with considerable saving in time. Dimensions and notes may in some instances be put on a sketch in long-hand. Frequent use of leaders is recommended. Sectional views for explanatory purposes are very desirable and should be dimensioned freely. Paper templates should be cut and fitted to curved portions, in order that more accurate dimensions may be taken. In this connection it may be well to point out that it is often better instead of trying to determine the exact curvature of an outline in the field, simply to coördinate various points on the curves from base lines which may be set up easily in the field, and leave the form of the curve to be worked out in the drafting room when the working drawings are being made.

**SUGGESTED PROCEDURE.** — Since all sketches are for temporary purposes and do not go to the shop man for his use in building the machine or structure, many short cuts and variations may be resorted to in securing the desired results. A few of these are listed below. Others will suggest themselves to the alert and skilful sketcher.

1. When objects are complicated by small detail at certain places, the sketches may be enlarged at these points in reference to the rest of the object, and the detail thus shown in its entirety.

2. When objects are symmetrical about one axis, only one-half of the object need be shown; if symmetrical about two axes at right angles to each other, only a quarter need be shown.

3. Spokes of wheels and teeth on gears may be shown by simply drawing one of either and indicating the total number. Rims and bands of all kinds may be treated in a similar way by simply drawing an outside circle and a cross section of the solid portion.

4. Standard fillets, threads, and machine processes should be indicated by notes, and no attempt made to fix their size by actual dimensions on the sketch.

5. In many cases only one view is necessary, and no others should be drawn.

6. Different views of an object may be put on separate sheets, with clear notes explaining the direction from which each was taken.

7. Circles may best be drawn by first putting in a few dots on the circumference in each quadrant, and one on each center line. Errors in curvature will be discovered and corrected very easily by this method.



## CHAPTER XV

### REPRODUCTION OF ENGINEERING DRAWINGS

The greater part of this text has been devoted to a study of the science and art of making engineering drawings. A single drawing of an object, however, would be of very limited service, since only a few men could have access to it at the same time, and then they would all have to be at the same place. The different parts of a machine or structure are often fabricated in cities miles apart; hence, copies of the original drawing are very necessary. Several very satisfactory methods of duplication are described below.

**BLUEPRINT PROCESS.** — One of the most common methods of duplication of engineering drawings is the blueprint process, of which there are several variations. Only the more important ones will be considered in this text.

The original blueprint process, which was first discovered by Sir John Herschel in 1840, was introduced into the United States at



*(Courtesy C. F. Pease Company.)*

FIG. 1. Sun printing frame.

the Centennial Exposition in 1876. Briefly, the process consists in exposing a sensitized paper to white light through a negative,—usually a tracing of the drawing, and developing the exposed paper in water.

To make a blueprint from a tracing, the sensitized side of the paper is placed in contact with the tracing, with the ink lines out-



side or away from the paper, and then both are placed in a printing frame which can be rotated on a central axis so that the glass top is underneath while loading and holds the tracing and paper in firm contact while exposure to the light is made. See Fig. 1.

**EXPOSURE.** — The time of exposure depends both upon the intensity of the light and the speed quality of the paper. In strong sunlight, twenty or thirty seconds will give satisfactory results. One cannot set a definite time for sun exposures, however, because the light is so greatly affected by climatic conditions. With a single arc light, about two minutes will be required for ordinary rapid paper. Experience will enable one to determine the proper time of exposure, by observing the color of the paper projecting beyond the edges of the tracing. For uniformity in color, it is best to time prints with a watch, after the proper time has been determined experimentally by using small strips of blueprint paper.

**WASHING.** — After exposure, the tracing is carefully laid aside and the print developed by washing in water. In running water the time of washing should be about three to five minutes. In a flat pan where the water is not constantly changing, the time should be about ten to fifteen minutes. When the print is thoroughly washed it is hung up to dry. The print should show clear white lines on a deep blue background.

**INTENSIFYING.** — Occasionally, it will happen that a print has been over exposed. Upon developing, the white lines appear with a blue tinge, or they may scarcely appear at all, and the blue field has a mottled gray appearance. Such a print may be restored by washing in any oxidizing solution, usually potassium or sodium bichromate. The lines will then become pure white and the remainder of the paper an intense blue. The print must be washed in water again before it is hung up to dry.

**PAPER.** — In the preparation of sensitized paper, the paper used should be pure white and free from traces of sulphur and wood pulp. It must be properly sized, tough, fairly hard, not too absorbent, and not too heavily grained.

**SENSITIZER.** — The sensitizing solution is composed of ammonia-citrate of iron and potassium ferricyanide. The proportions of the two substances can be varied through a wide range and still produce satisfactory results. A combination frequently given is as follows:

Ammonia-citrate of iron,  $((\text{NH}_4)_2 \text{H Fe} (\text{C}_6\text{H}_5\text{O}_7)_2)$  1 oz.; water 4 oz.

Potassium ferricyanide,  $(\text{K}_3 \text{Fe C}_6\text{N}_6)$  1 oz.; water 4 oz.

If these two substances are placed in separate, dark-colored, well-stoppered bottles, they may be kept for a long time. To sensitize the paper, mix equal volumes of the two solutions and apply to the paper with a camel's hair brush, stroking first in one direction, and then at right angles thereto. This must be done in a darkened room, and the paper allowed to dry in a cool, dark place. When dry, the paper presents a pale green color. The more rapid papers contain uranic salts in addition to the above.

**CHEMISTRY OF THE PRINTING PROCESS.** — The two soluble chemicals, ammonia-citrate of iron and potassium ferricyanide, when in solution and away from the light, do not act upon each other. Therefore, if an unexposed piece of blueprint paper should be washed in water, the chemicals would simply be dissolved off, leaving the white paper. Under the action of light, the two compounds act upon each other, thereby reducing some of the ferric iron to an insoluble ferrous state and forming either Turnbull's blue or Prussian blue. These compounds adhere firmly to the paper. Hence, where the light shines through the tracing, this reducing action takes place, but under the opaque lines of the drawing there is no action. When the print is developed in water, the unchanged chemicals are washed away, leaving the white paper exposed, while on the remaining part the blue precipitate is deposited. It will be noted that the chief chemical action involved in this process is that of reduction.

The intensifying process, on the other hand, is an oxidizing action. It is used when the print has been "burned," that is, when it has been exposed too long and the reduction process has been carried too far. By washing the print in an oxidizing solution the over-reduced iron compound is restored to Turnbull's blue and a good print is obtained. Sodium bichromate is the oxidizing agent most frequently used.

If a print has been underexposed, as evidenced by a pale blue color after washing, nothing can be done to retrieve the print and it should be discarded.

**BROWNPRINT PROCESS.** — It is sometimes desirable to make prints on which the lines of the drawing appear blue and the background white. This may be accomplished by first making a negative from the tracing on sepia or Van Dyke paper, so-called, and then using this negative, instead of the tracing, with the regular blueprint paper. In preparing sepia paper, a very thin, tough paper is coated with a solution of potassium-sodium tartrate, citric acid,

ferric oxalate, and silver nitrate. The composition of the sensitizer may be varied as to proportions and also as to contents. The action of the light is the same as in the case of blueprint paper, the ferric salt being reduced as before. The precipitate formed in this case, however, is a deep brown.

To make a sepia negative, the tracing is placed in contact with the sensitized side of the paper, the ink lines being turned in next to the paper. After exposure, which must be somewhat longer than for blueprints, the sepia print is washed in water. The color of sepia paper before exposure is a light yellowish green, which upon proper exposure turns to a light bronze color.

In addition to being developed in water, which turns it a midnight brown, the print must be passed through a fixing bath of hyposulphite of sodium. This makes the print permanent and seems to make the color denser. If the "hypo" solution is too strong, it will have the effect of bleaching the print.

When the print has dried it must be "transparentized" by rubbing the back with an oil which is especially prepared for the purpose. A satisfactory "transparentizing" oil may be obtained by making a solution of white vaseline and banana oil or benzine. The oil makes the lines of the print translucent, while the remainder of the surface is left opaque. This print, which is now a negative in every sense of the word, may be used in place of the tracing. The oiled side must, of course, be placed away from the blueprint paper to prevent spotted prints and to give positive prints.

An excellent negative may be made by printing with the ink lines of the tracing away from the sepia paper, as is done when a tracing is used with blueprint paper. Such a negative has the additional advantage of being readable from the face side. It should be transparentized on the front side.

**BLUE-LINE PROCESS.** — A blue-line print can be made directly from the tracing if the paper is coated with a solution of gum arabic, ammonia-citrate of iron, and chloride of iron. The method of printing is the same as for blueprints. Instead of developing in water, however, the print is developed in a solution of potassium ferrocyanide. This developer acts upon the ammonia-citrate of iron, which has been unaffected by the light under the black lines of the drawing and produces a blue precipitate. After passing through the developer, the print is washed in water.

**REPRODUCING TRACINGS.** — It is also possible to make tracings from other tracings, by chemical means, which are identical with

the original in all respects. This is accomplished by the use of a sepia negative and "See Bee Cloth" sold by the American Blue Print Company of Chicago. No special apparatus is required to



*(Courtesy C. F. Pease Company.)*

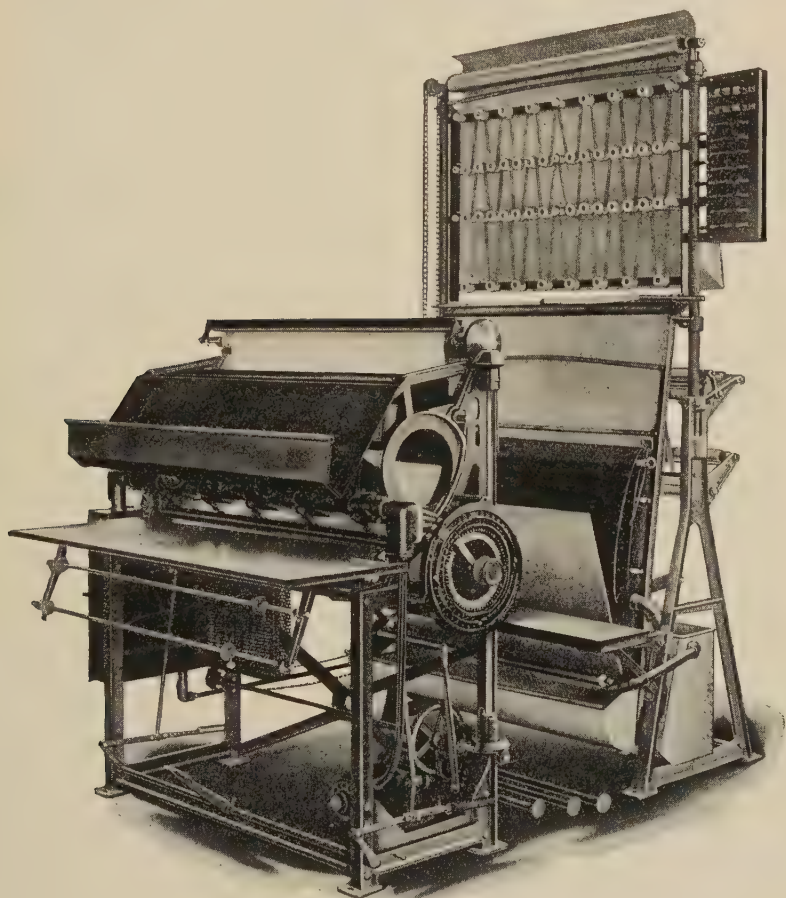
FIG. 2. Arc light blueprinting machine.

make these tracings, and full directions for development may be obtained from the company.

**BLUEPRINTING MACHINES.** — In every progressive office where there is much blueprinting to be done, the old sun frame has been replaced by a blueprinting machine, either of the vertical cylindrical type shown in Fig. 2 or of the continuous type shown in Fig. 3. In the cylindrical type the light moves up and down through the cylinder past the print, while in the continuous type the prints move past the light.



**PHOTOGRAPHIC REPRODUCTION.** — When a copy of a drawing is desired for record only, a reproduction may be made by a photographic process, which will make direct copies of any drawing or printed matter, whether in single sheets or in book form, without



*(Courtesy C. F. Pease Company.)*

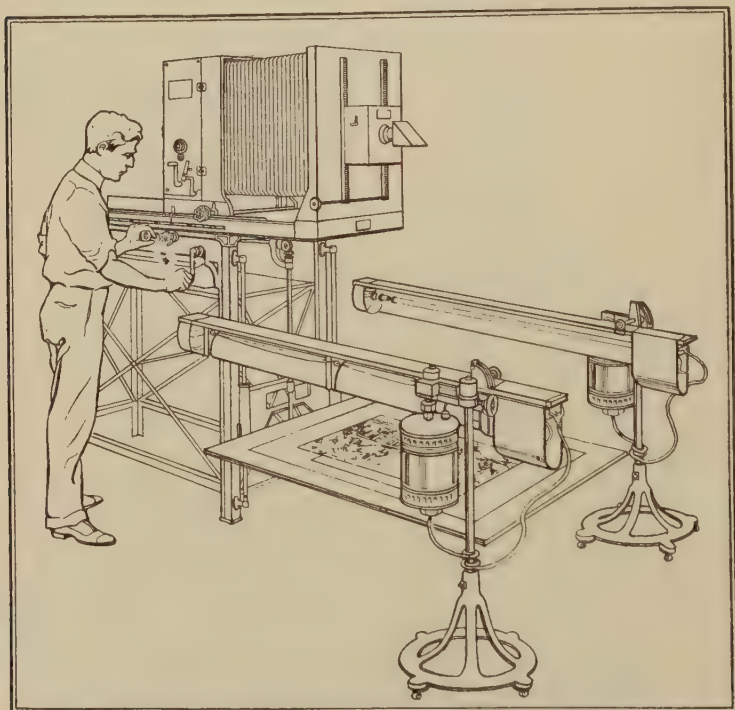
FIG. 3. Continuous blueprinting machine.

the use of negative plates, films, or dark rooms. There are several such machines on the market, in which the lens focuses the images directly upon a sensitized paper which is then developed and fixed within the machine itself by turning various cranks and levers. One of these machines is shown in Fig. 4. The machines are made



in several sizes, one of the larger sizes making a print 11"  $\times$  14". Drawings may be enlarged or reduced within the limits of this print.

**HECTOGRAPH.** — Another method of reproducing small drawings, sketches, and notes is by means of the hectograph. Various adaptations of this old method, arranged in convenient forms, are now on the market under different trade names, and they are quite



(Courtesy Photostat Corporation.)

FIG 4. Photostat.

satisfactory where less than one hundred and fifty copies are required. Such a copying pad may be made by preparing a gelatinous base, consisting of an intimate mixture of glue and glycerine in the ratio of one to four. For a 9 by 12 pad, 4 ounces of glue (flakes) and 1 pint of glycerine will be enough. Dissolve the glue in 1 pint of cold water, and when it is soft and has absorbed all of the water, add the glycerine and let the mixture come to a boil, stirring it the while to prevent burning. As soon as it comes to a

boil, pour it out into a shallow pan and skim off all bubbles as it cools, so that it will harden with a smooth surface.

A special hectograph ink, carbon paper, or typewriter ribbon must be used, with a glazed paper, to make the original copy. The lines should be comparatively thin, but of uniform weight throughout, and must be allowed to dry thoroughly before using.

To make duplicates, lay the original face down upon the gelatin base, rub it firmly with the hand, to insure a uniform contact, and allow it to remain from one-half minute to two or three minutes depending upon the number of copies desired. Remove the original and place upon the hectograph a sheet of unglazed paper. Rub it to insure uniform contact and remove. As many copies may be made as desired, within a maximum limit of about two to three hundred. As soon as the copies have been made, the hectograph should be washed with a soft rag and water to remove the surplus ink. As soon as it is dry, it may be used again.

**LINE ETCHINGS.** — To reproduce line drawings in great numbers, e. g., illustrations in textbooks, the etching process is used. The drawing to be reproduced is photographed in the usual manner, the size of the negative usually being made from one-third to two-thirds the size of the original. A print from this negative is then made, by exposure to "white" light, upon a sheet of planished zinc or copper coated with gelatin and bichromate of potash. This coating is soluble in water unless it has been exposed to the light. Hence, where the light has passed through the lines on the negative, hard metallic lines will remain on the zinc or copper plate. The plate is then subjected to heat to make the hard gelatin lines acid-resisting, after which the face of the plate is sprayed with acid which eats down all parts except the portion protected by the hard lines of gelatin. The plate is then mounted on a block of wood and is ready for printing.

**DRAWINGS FOR ETCHINGS.** — The drawing for an etching should be made upon a smooth-surfaced, white paper, or on tracing cloth which may be backed with white paper. The ink used should be a dead or glossy jet black. Almost any of the prepared drawing inks now on the market are satisfactory. As a rule, the drawings are made larger than the desired finished size of the etching and then reduced photographically. They may, however, be kept the same size or even enlarged. It should be borne in mind that reduction does not eliminate the faults or blemishes in the drawing. Nevertheless, in the case of one-half or greater reductions, the slight

irregular waves in lettering will disappear almost entirely because of the failure of the eye to detect such small imperfections.

The weight and spacing of lines must be carefully considered. The lines themselves, except very thin ones, are reduced in width

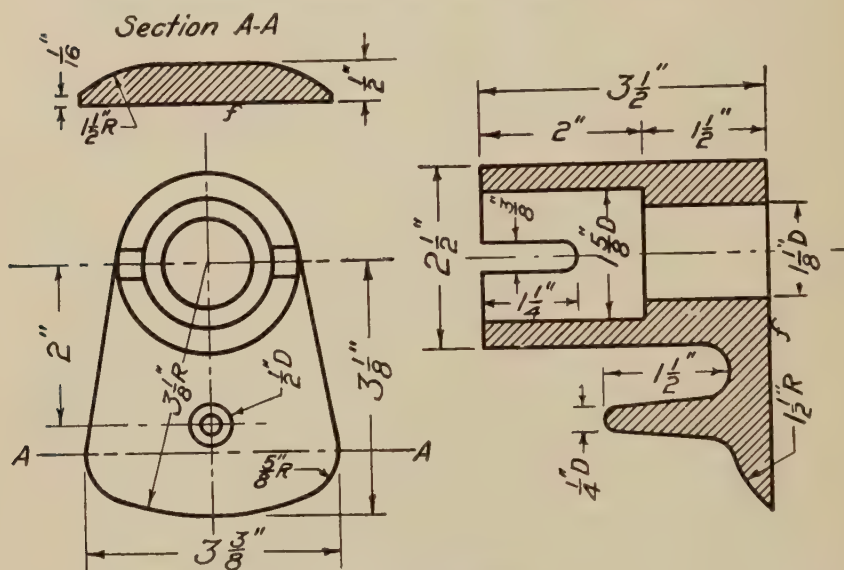


FIG. 5. No reduction.

hence the greater the reduction the heavier the lines should be made. In cross-hatching and shading, the lines should not be made too heavy or placed too close together, for if they are, a heavy black

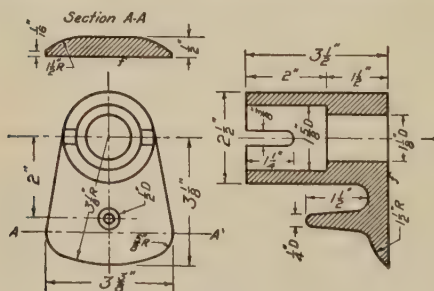


FIG. 6. Half reduction.

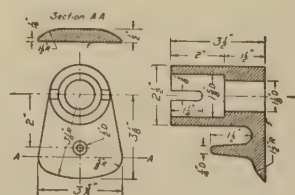


FIG. 7. Two-thirds reduction.

area will appear on the print. The spacing of lines should also be in proportion to the reduction. Figures 5, 6, and 7 show the effects of progressive reductions of a drawing.

**HALF-TONE PROCESS.** — The zinc or copper process, outlined in the preceding paragraphs, cannot be used to represent varying tones of black unless these are shown in pen lines on the original drawing. This can only be done by means of small dots or lines, which by their varying weight produce an imitation of tones, hence, the name *half-tone*. The half-tone process is quite similar to the etching process described heretofore, except that the original negative is made through a screen which is placed quite close to the negative. The screen is made by ruling lines on a waxed glass plate and then etching them in with acid. The plate is then cleaned and the etched lines filled with an opaque substance. Two plates are cemented together with Canada balsam, so that their lines are at right angles to each other, thus forming a screen where the light can penetrate only the little squares between the lines. The number of lines varies from fifty to three hundred to the inch. The coarser rulings are used for newspaper work.

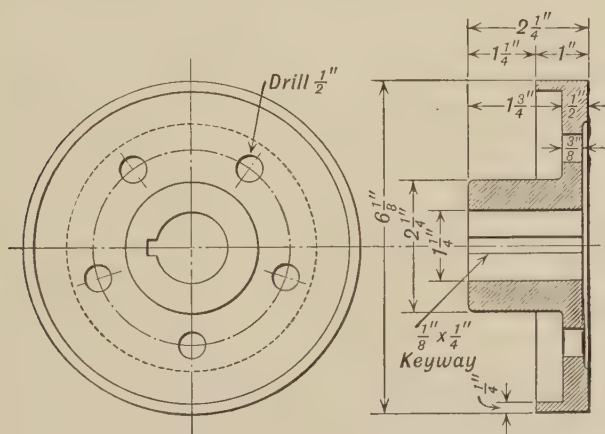


FIG. 8: Wax process reproduction.

**WAX PROCESS.** — Another method of reproducing line drawings is called typographic etching, or the *wax process*. A blackened, waxed copper plate has the drawing either photographed upon it or transferred to it by rubbing down from a tracing. The lines are then incised upon the wax, and later the space between the lines is built up with more wax. This forms a mold from which an electrotpe may be made. The draftsman may also make the drawing directly upon the wax surface from a rough sketch or copy. This method, however, is not recommended, since the draftsman



may not be familiar with the subject of the drawing and errors are likely to be made. Prints from electrotypes made in this way are always very uniform and neat in appearance, but they lack the life-like tone of line drawings and are more expensive. Figure 8 illustrates the character of cuts made by this method.

**LITHOGRAPHIC PROCESS.** — The lithographic process is rarely employed in reproducing engineering drawings, except maps. The drawing is reproduced on a lithographic stone, either by photography or by transfer through the rubbing process, and then the prints are made from the stone or indirectly by an offset method. The stone used is a product of the Saar valley in Germany, almost the only part of the world in which it is found in suitable quantity.

Patent Office drawings are all reproduced by the photolithographic process and printed in the Official Gazette. This is one reason why the details of such drawings are explicitly specified in the Rules of Practice of the Patent Office. The process is a very tedious and expensive one, if the drawings are not well standardized.

**OZALID PROCESS.** — A new process of reproducing drawings, called the Ozalid process, was invented in Germany and introduced into the United States in 1923. This process gives a positive print directly from the tracing. The lines of the drawing come out a deep maroon color on a creamy white back ground. The ozalid print, therefore, possesses all of the advantages of the blue line print and has the additional advantage of being true to scale, since the process is entirely dry and does not involve the usual washing procedure with its consequent shrinking of the paper.

The Ozalid process is based upon the fact that Diazo-oxides are destroyed by the action of light; and on the further fact that if certain Azo colors are added to the emulsion which are not subjected to the action of light, such Azo colors may be permanently fixed upon the paper by subjecting them to the influence of alkalies.

The process of making an ozalid print consists of two steps, namely, exposure to light and development. The exposure is made in the same way and for a somewhat shorter time than for ordinary blue print paper, but the development is made by exposing the print to the fumes of ammonium-hydroxide (ammonia-water). Forty or fifty prints may be rolled together and developed at the same time. Five to ten minutes are required for development.



## PART II

---

### CHAPTER XVI

#### DESIGN

In the introductory chapter of this text, a careful attempt was made to point out the true relation of the draftsman and of fine draftsmanship to the engineer and engineering practice. It was stated that the one is simply a stage or step in progressing to the other; that drawing is a graphical medium through which the engineer expresses himself, in the same way as the written or verbal language is a medium through which he conveys his ideas to others.

Nevertheless, when the terms draftsman and engineer or drafting and engineering are synonymously used, as they often are, it must be thoroughly understood that it is the element of engineering design which differentiates the one from the other. This term, design, has been used frequently heretofore in this text, but it has been left undefined until now. Before elaborating this point, however, it should be stated that there may be, and truly is, a large group of men who practice only the art of drafting and are not, therefore, engineers or architects in the sense that they create or design new things. This is simply because such individuals do not combine their skill and knowledge of drafting with a knowledge of the well-established principles of physics and mechanics; or, more precisely perhaps, they limit their field of activity to one phase of design, namely, empirical or conventional design.

**DESIGN.** — As stated in previous sentences, it is essential for the draftsman to combine his knowledge of the principles of projection and approved drafting standards with various elements of engineering design. These elements of design are commonly thought of as embodied in two main divisions, called theoretical or technical, and empirical design, respectively. Often the words "strict," "formal," or "exact" are used to convey the meanings implied in the term "theoretical," while the words "practical," "conventional," or "approximate" are used in place of "empirical."

**Technical Design.** — By technical engineering design we mean the application of known principles of mechanics, physics, chemistry, mathematics, and other sciences to given or assumed conditions of loading or applications of force, to the end that new structures and machines may be created, to meet new conditions which develop as man comes to understand the forces of nature and attempts to direct them to his comfort and use.

Such design presupposes a thorough knowledge of the fundamental sciences just enumerated. It also assumes that the direction and size of forces acting on or in the thing designed, and resulting from loads and pressures applied, are known. It further assumes that the distortion or displacement of the materials used in building up the actual machine or structure, due to applications of loads or forces, are known. In engineering language, these things are often indicated by the words "stresses and strains." Obviously, no textbook on engineering drawing should deal with any phase of technical or formal design, except in a most incidental way. This corollary, therefore, is strictly adhered to, both in the preceding chapters of PART I and in the chapters to follow in PART II.

**Empirical Design.** — In spite of what has just been said, there are certain considerations of form and convention, often inclusively expressed in the word "standards," which must be learned by the draftsman, quite apart from any formulae dealing with stresses and strains, and which are properly dealt with in books on drawing. Some of these factors are simply draftsman's rules to aid in unifying drawings turned out in different places; others result from codification of universal practices in technical design and are summed up in the term empirical design. So completely have these customary practices been standardized and thereupon conventionalized to a large extent in symbolic drafting, that it is imperative that both the engineer and the draftsman become fully acquainted with them. The use of the term "empirical design" in the restricted sense implied in the foregoing, does not, of course, exclude that type of design in which empirical formulae are used, although, for the purposes in mind in preparing this text, such design is more properly called "technical design."

To make these phases of empirical design, to which we are to direct our attention, clearer, and to bring out the draftsman's relation to them, a few references will serve:

**Clearances.** — The assembly of the various members of a struc-

ture on a pin, the arrangement of moving parts on shafts, the free space for installations of electrical and mechanical equipment, have to a greater or lesser extent been reduced to a set of empirical rules, which, of course, represent the results of long experience with, and observation of, the practical workings of good technical design.

Rivet Spacing. — In spacing rivets in standard structural forms, gage lines have been established for each size of flange; and rules have been laid down as to the size of rivets and the minimum distance from the edges of any plate at which they may be placed. These empirical rules are published in the various standard engineer's handbooks, with which every draftsman and engineer should be familiar.

Shop Methods. — Economical methods of handling the shop work on any piece of design must be known and kept in mind by the draftsman and engineer when the drawings are being prepared, in order that expensive shop operations may be eliminated as much as possible. Of still more importance in many respects is the question of whether the job can be done at all, if certain shop standards are not complied with in the drawings. Too often, drawings have to be sent back from the pattern shop because provisions for parting lines have not been made, lugs and bosses are improperly placed, and other simple details have been overlooked, which make the mechanical operations in the shop impossible. These considerations apply, of course, to all design, but they are cited here to emphasize the fact that to the draftsman they should be more or less empirical rules.

Building Details. — Akin to standard shop methods are those practices which have become universal in structural work, such as kind and type of lintels for various sizes of windows, ratios of thickness to height of wall, thickness of mortar layers for various purposes, and other similar details too numerous to mention.

From what has been said above, it is quite clear that before the would-be engineer can become a full-fledged designer, he must acquaint himself with what are commonly called the rules of design; or, in other words, he must understand *empirical design*. The purpose of the following chapters is to present those phases of Topographical, Architectural, Structural, Machine and other specialized Drawing which are properly limited to the fields of drafting and empirical design, together with a description of the correlated subject of Graphical Representations. Questions of technical design are omitted altogether, although definitions and glossaries of terms used are included.

## CHAPTER XVII

### CHART AND DIAGRAM DRAWING

Everyone who has occasion to read the following sentences will have had opportunity, at one time or another, to observe, and perhaps study, simple charts and diagrams which show in some graphical way the relations that exist between certain correlated facts, such as the price of cement per barrel for a series of years, or perhaps the number of people in the United States at each census period. These facts may have been represented by an irregular or smooth

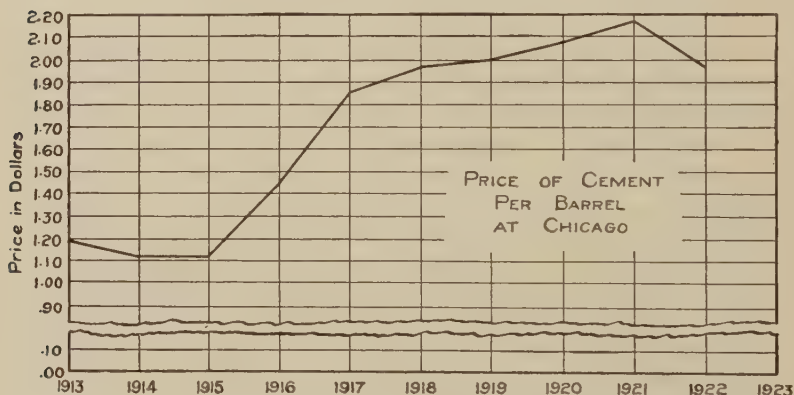


FIG. 1. Plane curves, data from Engineering News-Record, Vol. 90, page 43.

line as shown in Fig. 1 and the second part of Fig. 2, in the one case, or by a series of heavy, black lines, with lengths corresponding to the population at each time the count has been made in the other case. See the first part of Fig. 2. Experience shows, however, that few persons really have any adequate idea of the variety and uses of such graphical charts, and much less are they informed of the drafting problems involved in this important and fascinating field of graphical representations.

The engineer, above all other persons, should not only be well skilled in the manual technique of this kind of drawing, but also be versed in the fundamental principles and rules governing the use of this diagrammatic language. There are three chief reasons why this is so:



1. In creating new projects and designs, the engineer must first collect and tabulate, in some form or other, all the facts which are available bearing upon any feature of the new project or design. These facts may exist in the form of known laws of science, in sets of test data, in recorded observations of the action of similar projects or designs, and in various other forms. The salient features of these facts are very frequently best observed when properly marshalled in graphical diagrams.

2. Similarly, in the operation of existing engineering and industrial projects, the engineer must also have before him at all times

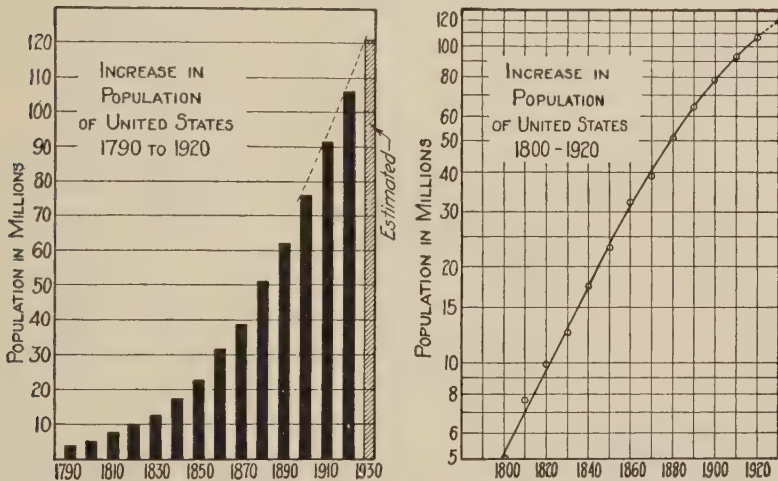


FIG. 2. A barograph and semi-logarithmic chart, (same data).

continuous records of those facts which will show just what is being done daily by the various units involved, whether they are men or machines; also, he needs to have those facts which show energy input and output, peak and low loads, progress of manufacture of various parts of a machine or structure, and a score of other details which will make possible the successful operation of the plant.

3. The engineer is often engaged in the task of reducing to mathematical form (equations) the law of action of some natural phenomenon as expressed by observed or test data. The best possible means of deriving such equations is by the use of plotted curves representing the data.

The business man also must have at his command huge arrays of



facts and statistics about each item affecting his particular business. Periodic fluctuations in supply and demand, tendencies toward cycles in price movements, discrepancies between sales and collections, are some of the facts with which the business man has to deal. All these must be collected and tabulated in such a way as to ensure easy reference to and interpretation of the various factors governing the operation of the business.

The most effective way of digesting and preserving the scientific, economic, and physical facts just mentioned, is by means of some type of Chart or Diagram. This may vary from a simple drawing containing only a series of straight lines, to very complicated diagrams of mathematical curves, or colored charts. Such a method of representing facts has been in use for many years; hence, a great number of variations of the few really fundamental types have been invented.

It is a well-known fact that the mind can easily comprehend, through the medium of the eye, a vast amount of correlated data if put into a properly designed chart or diagram. It is also known that there is a directness of appeal to the popular mind in a well-constructed and ingenious chart, that cannot be achieved by any other scheme. For this very reason, it is easy for the informed but unscrupulous to mislead others through the skilful but incorrect use of these same charts and diagrams.

It is not the function of this text to treat exhaustively of the uses and abuses of all kinds of graphic illustration. Those interested in going thoroughly into the numerous ramifications of this fascinating subject will be greatly aided by consulting some of the excellent works listed in the bibliography at the end of this chapter. Our purpose here is to classify the more common types and to discuss concisely the drafting problems involved. Both skill and versatility are required of the draftsman in the execution of these forms of the graphical language, and each must be applied with a degree of finesse almost as great as that required in the making of other kinds of engineering drawings. In fact, all of these forms of the graphical language are included in the commonly used term, Graphical Representations, which, except for this quality of inclusiveness, might have been properly used as the title of this chapter.

**GRAPHICAL REPRESENTATIONS.** — Broadly, such representations may be divided into two great groups: first, those showing the shape, size, and material of any tangible thing, such as a machine

or geometric form; and second, those showing facts, statistics, and laws, where a line, area, or volumetric symbol drawing is used to present a visual tabulation of the related facts and data. The first group is called *picture* or *projection drawing*, and has been studied already in previous chapters, under the headings of Orthographic, Isometric, Oblique, and Perspective Projections. The second group is called *chart* or *diagram drawing*, and is the kind of

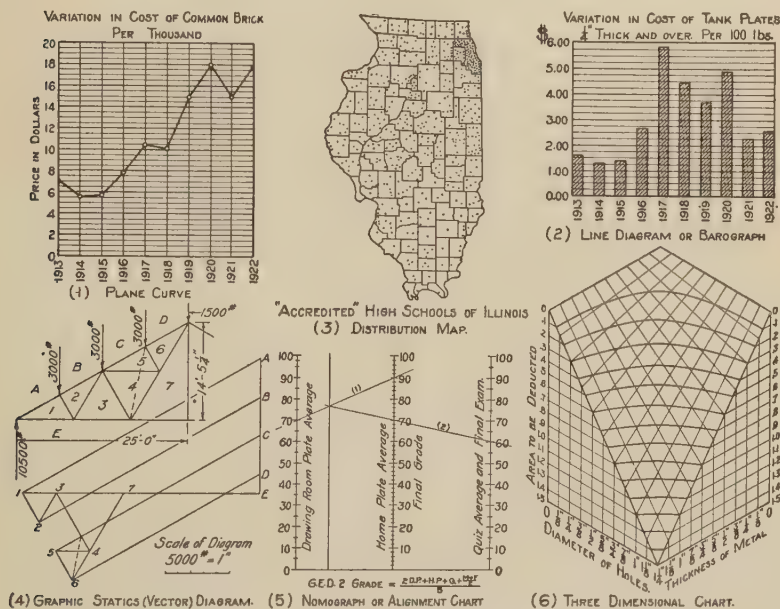


FIG. 3. Typical charts and diagrams.

graphical representation to which, as previously intimated, the paragraphs of this chapter are devoted.

**CHARTS AND DIAGRAMS.** — Figure 3 represents various types of technical charts and diagrams. The name of the class of chart or diagram, of which each cut is a typical example, is given in the following table in the order of the cut numbers.

1. Plane Curves — drawn on coördinate papers.
2. Line, Area, and Volume Diagrams and Charts.
3. Map or Distribution Charts and Diagrams.
4. Graphic Statics and other Vector Diagrams.
5. Nomographs, or Alignment Diagrams.
6. Three-Dimensional Charts and Diagrams.

It should be emphasized that, although the illustrations used are taken from technical fields, it would have been as easy to find illustrations in social, religious, and other realms for the first three groups. The last three groups apply almost exclusively to technical or scientific work. It should be pointed out further that, as far as everyday use is concerned, the words charts and diagrams are synonymous.

The first three groups of this table are of special interest to us in this text, since they deal with simple everyday laws and statistics. The last three groups require an intimate knowledge of Mechanics and Mathematics on the part of one who studies them understandingly, and, consequently, are here given space sufficient only for definition and illustration.

**PLANE CURVES.** — The term Plane Curves includes those diagrams or charts which express graphically, by means of one or more

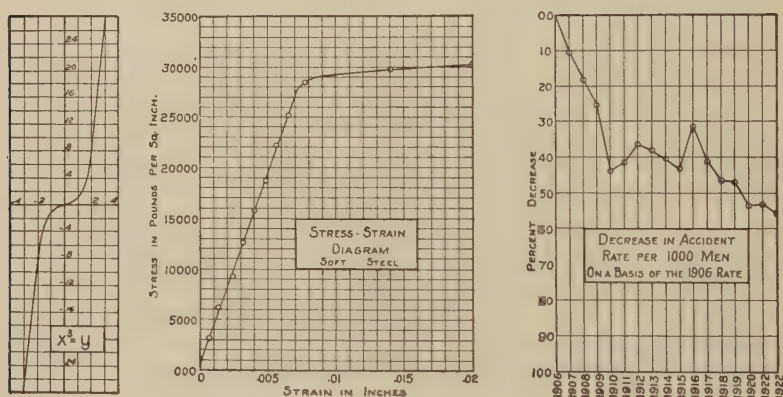


FIG. 4. — Plane curves.

continuous lines on coördinate paper, the known relations existing between two or more variables, such as time and distance, time and velocity, or pressure and volume. Because of this graphic quality of representation, they are often called graphs, especially by mathematicians. The graph proper may be a single straight line, a simple curve, a continuing series of straight lines or curves, or, in a few cases, a combination of both.

The usual graph is obtained by plotting or locating on coördinate paper a series of points which represent successive and simultaneous values of two variables. These simultaneous values of the variables are shown by the respective distances of the plotted

points to two coördinate axes, often called the X and Y axes. The graph line is drawn through, or approximately through, the various plotted points. Just how the graph line shall be drawn must depend upon the uses to be made of it, which uses will be discussed later.

The simultaneous values spoken of in the preceding paragraph may be derived by successive solutions of an algebraic formula containing two mutually interdependent variables, where values of one

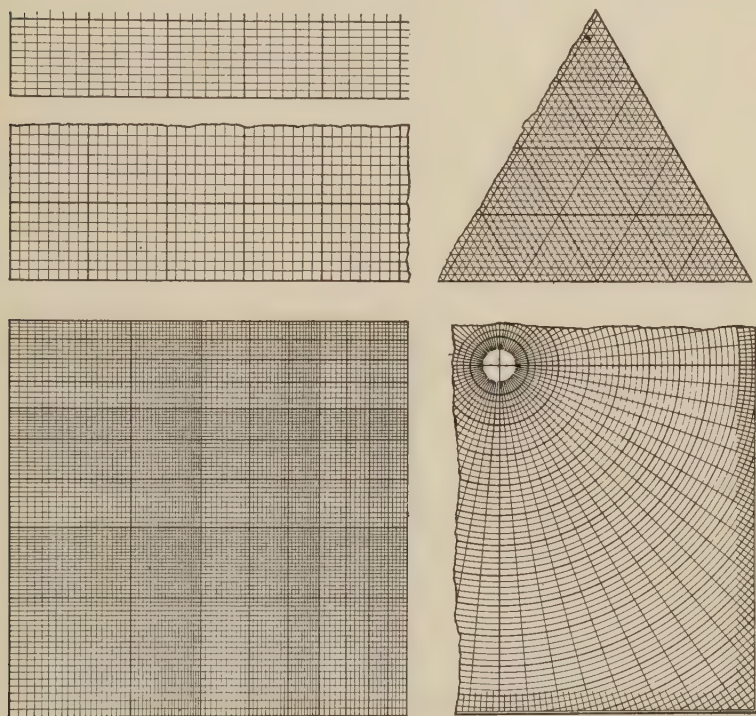


FIG. 5. Coördinate papers.

variable are assumed and substituted in the formula, and the corresponding values of the other are computed; or they may be obtained by taking readings on tests conducted in the field or laboratory; or by observing natural phenomena. Figure 4 illustrates each of these types of curves.

**Coördinate Papers.** — To facilitate the numerous measurements which have to be made along and perpendicular to the axes, and to obviate the use of the measuring scale altogether in many instances, sheets of paper called coördinate (cross-section in the trade) paper



can be purchased, already ruled or printed with horizontal and vertical lines which are some convenient unit of measure apart, such as one-tenth, one-hundredth, or multiples of one-sixteenth of an inch. Radial and circular rulings are also made. Figure 5 shows the common types of coördinate papers. They may be obtained in several colors of ink and in various weights and grades of paper.

The great majority of curves are drawn upon rectangular papers, although the other forms find wide usage for special purposes. Thus, for example, polar coördinate paper is used extensively in automatic recording devices, in illumination charts, and for equations written in polar coördinate form. Logarithmic paper is very useful in plotting curves of an experimental type since such curves can usually be reduced to straight lines upon this paper. See Fig. 26. Semi-logarithmic paper is useful where a rate of change is of primary interest rather than the actual numerical change. See Fig. 2.

**Locating and Marking of Coördinate Axes.** — Referring again to Fig. 4, it should be pointed out that the intersection of the coördinate axes is called the origin, or point of zero coördinates. Usually the lower left-hand corner of the ruled sheet is selected as the origin. The bottom line then becomes the X-axis and the left-hand line the Y-axis. All plus values of X are measured to the right of the Y-axis, and all plus values of Y are measured above the X-axis. If there should be negative values of either X or Y, then the axis affected should be moved up or to the right, as the case may be, to allow for the plotting of these negative quantities on the opposite side of the axis to the plus values. In such a case, the position of the axes should be indicated by heavy, black lines drawn over the colored coördinate lines. In fact, it may be of advantage in many instances to show the axes in heavy black, lines even though they coincide with the outside coördinate lines on the sheet.

If it is desirable to begin the lowest vertical coördinate, for instance, at a value considerably above zero, then the bottom line should be made slightly wavy; or, better still, it should be left as the original zero ordinate, and two rough lines drawn horizontally across the paper just above the bottom line, to indicate the omission of intermediate coördinate lines.

Measurements along or parallel to the Y-axis are called ordinates, while measurements along or parallel to the X-axis are called



abscissae. Hence, the distance of a plotted point above or below the X-axis is called the ordinate of the point; the distance of a point to the right or left of the Y-axis is called the abscissa of the point. The ordinate and abscissa, when referred to together, are called the coördinates of the point.

It will be noted, in using coördinate papers, that heavier rulings occur at regular intervals, such as at every tenth line, for instance. See Fig. 5. These coördinate lines are usually the only ones that are marked with numbers to indicate their distances from the zero axis. These numbers are not usually in terms of inches or millimeters and the like, but are in the units which the particular axis has been assigned to represent. For the Y-axis, these numbers should be put at the left of the vertical line representing this axis,

as a general rule; for the X-axis they should be put just below the horizontal line representing this axis. However, there may arise cases where the procedure of putting the markings inside the lines is convenient or necessary. This condition may occur when negative quantities are being plotted, or when the margins are small on the coördinate paper. If the curve passes over a large share of the paper and the paper itself is large, it is well to put the coördinate markings at both sides of the sheet and at the top and bottom.

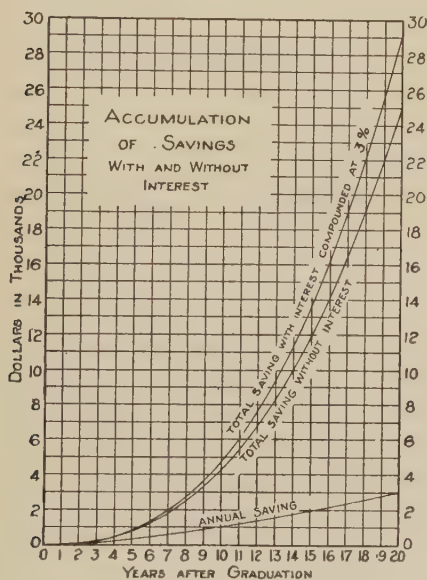


FIG. 6. Marking coördinate axes.

In addition to the numerical markings, there should be added, outside and parallel to them, a descriptive phrase telling what quantities the numbers represent, such as "Discharge in feet per second," "Time in minutes," etc. See Fig. 6. Where the paper has been cut from rolls, it may be well to add border lines to the sheet to give it a finished appearance. This is often done even on the standard-sized sheets of coördinate paper.

**Indicating Plotted Points.** — The particular methods of representing the plotted positions of the numerous individual sets of values of the variables on the coördinate paper, is, of course, somewhat empirical, but long usage has given sanction to the simple dot or circle wherever plottings are for one set of data only, or where no confusion will arise even though several curves are drawn on a single sheet of paper. Squares, triangles, crosses, and other signs may be used to keep several sets of data apart. In special instances, different colored inks may be used for the different sets of data, in which case the same colored ink should be used in drawing the curve as was used in plotting the corresponding points.

**Selecting Coördinates.** — When the variables are expressed in terms of X and Y — the generally used letters for unknown or variable quantities in algebraic formulae — the X-axis is taken horizontally and the Y-axis vertically, as has been explained.

When the variables are not expressed in terms of X and Y but are given in such terms as velocity in miles per hour, cubic feet per second, and the like, the first consideration in selecting the proper coördinate axis to represent one of the given variables finds its root in customs and current practices. Unfortunately, these things cannot be reduced to categorical statements and rules. We may, however, deduce a general principle upon which to base the majority of our selections of coördinates, which stated concisely in rule form is:

Plot values of the *independent* variable along the horizontal axis in all cases, unless weighty reasons make the reverse procedure necessary or desirable. The *dependent* variable will, of course, be placed on the vertical axis.

The general principle of coördinate selection, just given, agrees exactly with that for choosing coördinates for variables in algebraic formulae, since X is considered the independent variable and its values are plotted along the horizontal axis.

Figure 7 shows the same data used in Fig. 6 plotted with the time element on the vertical axis. The first part of the figure has the earliest time element, or zero ordinate, at the bottom of the sheet. The second part of the figure shows the time element plotted in a reverse manner. Reference to Figs. 6 and 7, simultaneously, show at once the misconceptions that are bound to arise if the time element is not put on the horizontal axis. Figure 6 gives the correct impression. The left diagram in Fig. 7 gives a wrong impression. The diagram on the right is an improvement over

the one on the left, but still gives a false impression at first sight. Although objectionable, the latter diagram can be made to function effectively if the reader will turn the page so that its left side comes at the bottom. The first diagram should never be used; the second is permissible but not advisable.

Along with the proper choice of axis for each variable, goes the problem of selecting the best distance on each axis to represent the

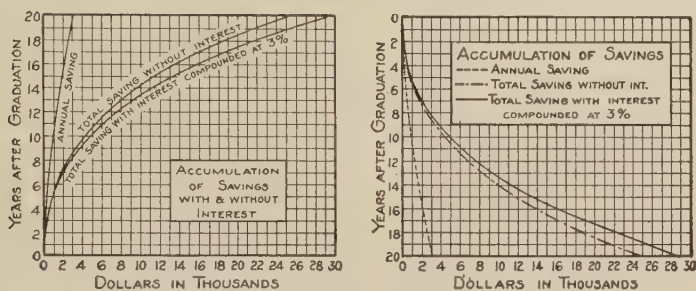


FIG. 7. Independent variable on wrong axis.

unit in which the corresponding variable is measured. Upon the final decision in this respect rests the whole matter of the slope of the curve on the paper.

**Slope of Curve.** — In general, it is easier to read values of each variable from curves that incline about 45 degrees to each axis than

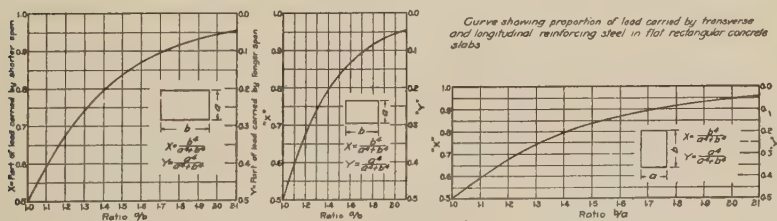


FIG. 8. Effect of coordinate selection on slope of curve and accuracy of readings.

it is to take such readings from curves that are nearly horizontal or vertical. The accuracy attained in drawing a curve, or in reading values from it after it is drawn, varies directly with the angle of slope from a 45-degree line. If the curve is to be used as a computation curve only, then a judicious change in the scale of units on one axis, to make it more nearly approach the ideal, without, of

course, making the unit of measurement too small for accurate use or too large to keep the curve on one sheet of coördinate paper, is often advisable. Figure 8 illustrates the effect of changing the scale of units on either axis.

If the curve is intended to convey impressions of tendencies only, through slope characteristics, then even more care must be exercised in the choice of axial units. It is clear that the impressions of the rate of increase of the variable obtained from a casual study

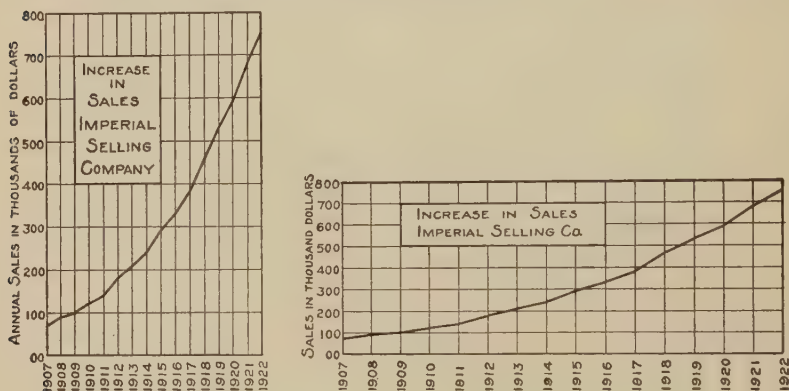


FIG. 9. Effect of coördinate selection on impression produced.

of the pair of graphs in Fig. 9 are very different in the two cases; yet both curves are plotted from the same data. Much can be made of these apparent differences for either good or bad purposes.

When the chief concern with any set of data is the *rate of change* rather than the actual numerical change, this can be best shown on semi-logarithmic paper. Rectangular coördinate plotting will give an erroneous impression of the change in rate of increase or decrease, as may be seen by a comparison of the two parts of Fig. 2. This effect is produced entirely apart from the scale selected for the coördinates.

**Drawing the Curve.** — As already pointed out, the graph itself may be a straight line, in which case the draftsman lays a straight edge along the plotted points and draws in the required line. If the points do not fall on a straight line, the draftsman must decide whether to draw a series of straight lines from point to point, or to draw an average straight line through some median position which will balance the points on each side of it against each other, or to use a smooth curve through each point, or to balance the points on a smooth median curve. To answer this question intelligently,



the draftsman must know the purpose for which the curve is being drawn. If the curve is to represent simple facts from which no generalization is to be made in the form of a mathematical law, it will be of one character; while if a law is to be derived from the data, the curve will have quite a different character, as explained in the following examples:

1. To draw the graph representing a law in mathematics which has been expressed by a formula. It will be found in such a case that all values plotted from numerous solutions of the equation will fall directly on a straight line or on a smooth curve. A series of discontinuous straight lines or short arcs of curves from point to point may not be used. The graph must pass through every point. See Fig. 10. In practice, the points are marked in pencil only and erased after the curve has been inked.

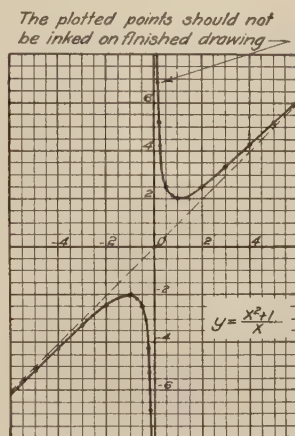


FIG. 10. Mathematical curve.  
(Curve through all points.)

2. To draw the graph representing data secured by tests or observations of any natural phenomena. If the data at hand have been taken very accurately and they represent some law of science or nature which can be reduced to mathematical language, then the conditions of (1) will obtain. This is unlikely to be the case. More often an average curve must be found which will pass close to each plotted point and balance those on the one side with contiguous ones on the other side of the curve. The simplest method of doing this is to make the shortest distances from the points to the curve the same on each side and as small as possible. This will mean, in some cases, that two and three points on one side of the curve will have to be balanced against only one point on the other side of the curve. Stated in another way, the sum of the distances from the plotted points to the curve must be the same on each side of the curve. Judgment must be exercised in applying this method, however, since some points have been located with greater accuracy than others, through more careful ob-



servation of the facts expressed by certain portions of the data, and hence should be given more weight in the balancing.

Points on opposite ends of a curve cannot be used to balance each other, as they are too little related in the data. Obviously wrong points should be disregarded altogether, but mere doubt is not enough to reject a point. Groups of thickly plotted points on the paper may be given more weight than points scattered far apart, in determining the general characteristics of the graph.

In some cases it will be found that the observed data cannot be represented even approximately by a smooth curve, in which case the only thing to do is to connect the points by a series of straight lines. This condition occurs, of course, when there is little mutual relation between the variables being represented. A good example is shown in Fig. 11, where the amount of rainfall for each

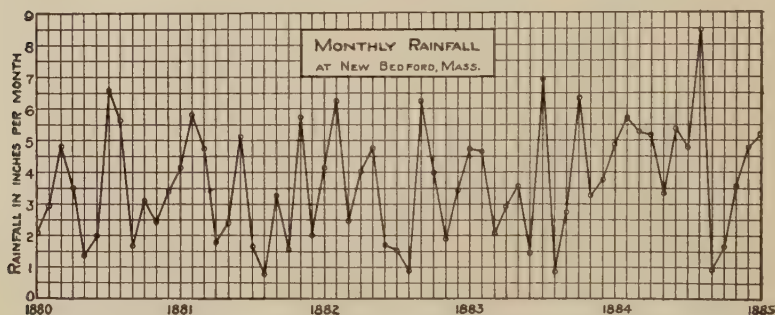


FIG. 11. Rainfall curve. (Curve through all points)

month at New Bedford, Mass., for the years 1880 to 1885, inclusive, has been plotted. Not even an approximate average curve is possible in this case, since very little relation exists between the successive months. Such graphs fall more logically into that group of diagrams classed as Line Diagrams, to be discussed fully in subsequent paragraphs.

3. To draw the graph representing limiting conditions outside of which values of either variable will be found only very rarely or not at all. The second part of Fig. 12 so clearly typifies this kind of use of the plane curve that further comment is unnecessary. It is important to point out that this curve is derived from the same data used in the first part of the figure and that two methods of representing data, as here employed, contribute much to a true understanding of the facts.

The following points, quoted from the preliminary report of the Joint Committee on Graphical Representation, are excellent guides to the general practice of curve drawing:

### GENERALITIES

1. The general arrangement of a diagram should proceed from left to right.
2. Where possible represent quantities by linear magnitudes, as areas or volumes are more likely to be misinterpreted.
3. For a curve, the vertical scale, whenever practicable, should be so selected that the zero line will appear on the diagram.
4. If the zero line of the vertical will not normally appear on the curve diagram, the zero line should be shown by the use of a horizontal break in the diagram.

### WHICH LINES TO EMPHASIZE

5. The zero lines of the scale for a curve should be sharply distinguished from the other coördinate lines.
6. For curves having a scale representing percentages, it is usually desirable to emphasize in some distinctive way the 100 per cent line or other line used as a basis of comparison.
7. When the scale of a diagram refers to dates, and the period represented is not a complete unit, it is better not to emphasize the first and last ordinates, since such a diagram does not represent the beginning or end of time.
8. When curves are drawn on logarithmic coördinates, the limiting lines of the diagram should each be at some power of ten on the logarithmic scales.
9. It is advisable not to show any more coördinate lines than necessary to guide the eye in reading the diagram.
10. The curve lines of a diagram should be sharply distinguished from the ruling.

### AUXILIARY INFORMATION

11. In curves representing a series of observations, it is advisable, whenever possible, to indicate clearly on the diagram all the points representing the separate observations.
12. The horizontal scale for curves should usually read from left to right, and the vertical scale from bottom to top.
13. Figures for the scales of a diagram should be placed at the left and at the bottom or along the respective axes.
14. It is often desirable to include in the diagram the numerical data of formulas represented.
15. If numerical data are not included in the diagram it is desirable to give the data in tabular form accompanying the diagram.
16. All lettering and all figures on a diagram should be placed so as to be easily read from the base at the bottom, or from the right-hand edge of the diagram as the bottom.
17. The title of a diagram should be made as clear and complete as possible. Subtitles or descriptions should be added if necessary to insure clearness.

**Technique of Curve Drawing.** — In Figs. 4 and 11, it will be noticed that the curve has been drawn up to each circle representing a plotted point, instead of being passed through the circles as one continuous line. The purpose of this is not only to present a neater appearance, but also to preserve the coördinate values of the point, so that they may be read accurately from the center of the circle. In the case of curves plotted from algebraic formulae, the points used in locating the curves are not inked in, and all trace of their pencil positions is removed. Such curves are gen-

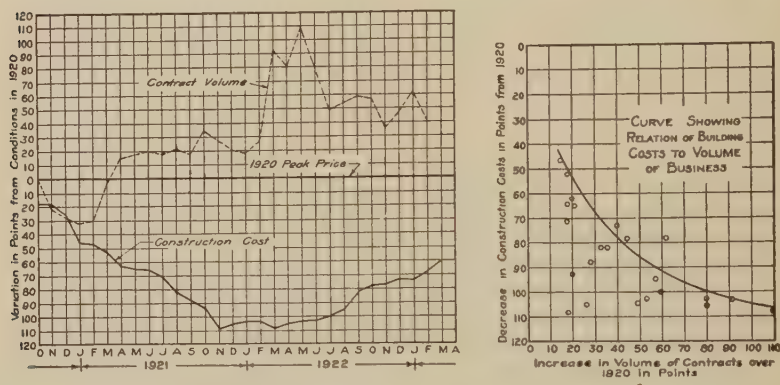


FIG. 12. Comparison and limiting curves.

erally used for computation purposes, and the entire line must be available for readings.

The curve itself should be a fairly heavy line, so that a good contrast is made with the coördinate lines. If, however, the curve is drawn definitely for the purpose of furnishing numerous and accurate readings, as would be the case with a calibration curve, then a sharp, fine line is justifiable.

If several curves representing different sets of data are drawn on the same sheet, it is well to distinguish between them by the use of dot and dash, dash, or even dotted lines, in addition to the full line commonly used. A key to the meaning of each kind of line may be lettered on the sheet, or a descriptive word may be put on the curves themselves. Too many curves on a single sheet should be avoided.

When coördinate paper is being ruled in the drafting room on tracing cloth or drawing paper, care must be taken not to space the lines too close together. The eye is able to interpolate a space of

one-fourth inch as accurately as is necessary for most curve plotting.

If the graph is to be used for reproduction purposes, it will be best to draw it on the opposite side of the paper from the printed coordinate lines. Erasures on the right side of printed commercial papers remove the printer's ink, and it is very difficult to repair such damage satisfactorily.

**Titles and Legends.** — Somewhere on the curve diagram, a neat title should be lettered, in much the same way as on working drawings, giving the name of the curve, the source of data from which it was plotted, date, and name of draftsman or investigator. For added effect, a rectangular area may be cleared of all coordinate lines by the use of alcohol, and the title may then be printed in this open space and the area enclosed with black borders. Legends are sometimes printed on the curve itself to explain it in greater detail than is done in the title. It will often be necessary also to add other informational legends about the sheet, in order to make unmistakably clear what the curve is and what information it may give the observer. Notes should be added to explain any great irregularity which appears in the plotted points, or which surrounds the taking of the curve data. A key to the various symbols used should also be included. Equations of curves and tabulated data are sometimes included.

**LINE DIAGRAMS (BAROGRAPHS).** — It is often necessary to present statistical data in some diagrammatic form which will be understood by everyone and which will give a simple and complete picture and summary of the facts to be presented. Single straight lines and curves, such as were discussed in preceding pages, will not be suited at all to the purpose mentioned, because everyone does not have an understanding of curve characteristics, and the picture qualities of the curve itself are almost nil to the average person engaged in the non-technical pursuits of life.

If, however, the data at hand can be separated into well defined divisions, such as periods of time — days, weeks, and months of the year — or units of size, like companies in a regiment, weight of persons at different ages, etc., then the quantitative aspects of each division of the data may be represented by a chart of consecutive heavy lines or bars, whose lengths shall correspond to the respective quantities to be compared. Such a series of bars is called a Barograph or Line Diagram. The width of the representing lines has nothing to do with the size of the quantities represented, and should



not be so great that the observer secures an impression of comparative areas instead of comparative lengths. The width should be great enough, however, to make each line easily distinguishable at the distance from which the observer will view it. In any case, the bars must all be of the same width on a single diagram. Figure 13 illustrates the principle of arrangement of a line diagram. From this typical illustration, several general deductions, applicable to all cases in which the line diagram is to be used, can be tabulated:

1. Commercial coördinate papers are of little use in line diagram work, since the chief purpose of such a diagram is to leave a comparative picture in the mind of the observer, and numerous coördinate lines in the background of such a picture have no additive effect in the process of comprehending the diagram. The heavy bar-lines must be spaced equally along the base line, however, and coördinate lines are helpful for this purpose, as well as being an aid in fixing the length of the bars. Since the end coördinate of each bar is the only thing of importance in reading the diagram quantitatively, it will be found advantageous simply to rule in lines at regular intervals perpendicular to the bars and extend them across the diagram to the coördinate line representing the scale of quantities. They may or may not be extended to the opposite side of the diagram. Fig. 14. Lines parallel to the bars may be omitted altogether. See Figs. 2 and 13. When the unit and kind of quantities represented on either or both axes are readily understood, the descriptive phrase, always found on line diagrams, telling what quantities the units represent, may be omitted. See Fig. 14. Otherwise, these descriptions should be included. See Fig. 13.

2. When the data to be represented are expressed in numerical quantities for certain definite periods of time, the heavy lines or bars should be drawn vertically, and the units of time should be marked off on the horizontal base line. See Fig. 14. The naturalness of this arrangement is apparent when one recalls that time, in everyday language, is spoken of as a sort of horizontal progress, while the functions depending upon time have their "ups and downs," as is clearly shown by the diagram. Size and proportions of the diagram may compel the placing of time elements on the vertical axis, thus making the bars horizontal. In such cases, the earliest period of time should be put at the top, so that the diagram may be read from the left side and the time periods may appear in the natural way. See Fig. 13. Other quantitative values, which are not associated with "up and down" descriptive terms or with



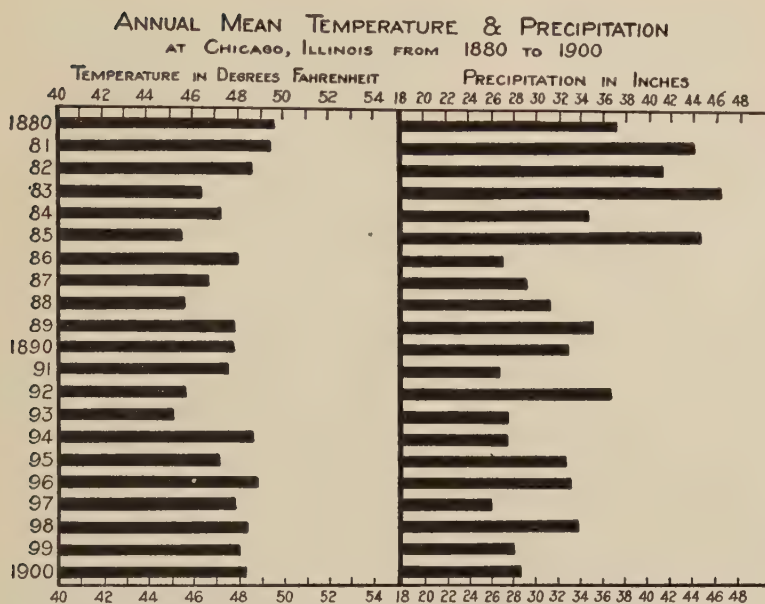


FIG. 13. Barograph, time elements on vertical axis.

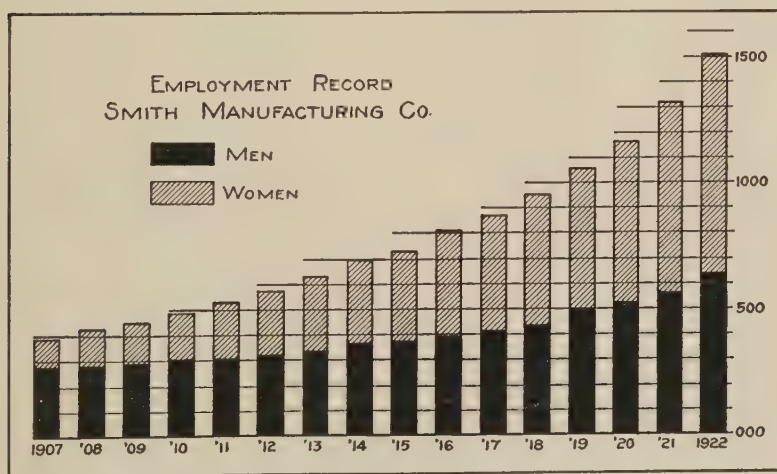


FIG. 14. Barograph, quantities additive.

time elements, should be treated according to the rule cited previously in regard to the location of the independent variable on the horizontal axis, in so far as practicable.

3. When an attempt is being made to fix exact numerical quantities in the mind of the observer, in addition to the comparative qualities expressed by a line diagram, the specific values should be written along or at the end of each bar. Even the practiced eye does not readily grasp and transfer specific values to the mind when they are taken from a single base scale on which they can be read only approximately, as shown in Fig. 14.

4. When each main unit of data is composed of several subclasses, such as the labor of adult men and women and children of adolescent age, these facts may be clearly expressed by subdividing each bar into the proper proportions to fit the conditions. This has been done in Fig. 14. Black and white lengths can be con-

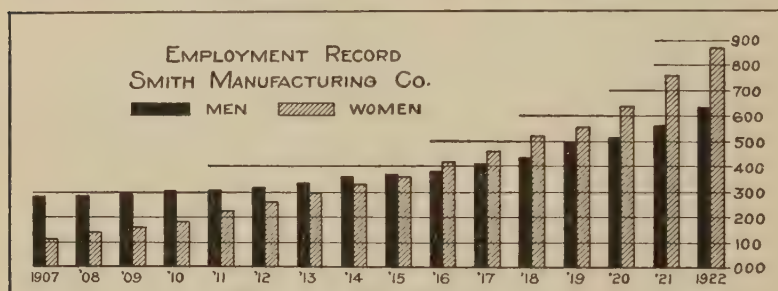


FIG. 15. Barograph, quantities comparative.

trasted with variously cross-sectioned lengths. Colored inks may also be used. Another scheme often resorted to is that of dividing the width of the bars into equal parts according to the number of factors to be represented, and extending each part of the bar the proper length. See Fig. 15. The first scheme is additive, rather than comparative in effect, while the second is simply comparative in its results. Both make it unnecessary to construct separate diagrams for each factor involved.

**AREA AND VOLUME DIAGRAM.** — Practically all data suitable for representation by any form of chart or diagram should be shown by a curve diagram, or they should be put into a barograph as just explained. In some cases, however, an area or volume diagram may be better suited to the purpose. This will occur when the differences between the quantities compared is very great, and

where the purpose of the comparison is simply to impress the observer with the fact of large and small magnitudes. For example, the cross-section of an electron and an orange could be compared better by this method than by a barograph. See Fig. 16. An area diagram may also be used profitably when the quantities to be compared are themselves areas and can be superimposed upon one another, to scale. The eye can easily compare sector areas of a circle, and a square is not difficult of interpolation when broken into several subdivisions. See Figs. 17 and 18.

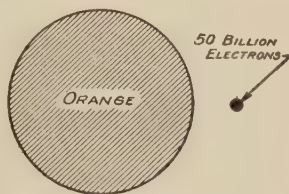


FIG. 16. Comparative area diagram.

A very effective area diagram, shown in Fig. 19, has been made up from the report of tests conducted at Cornell University and published in *The Country Gentleman*, June 7, 1919. The effect of the several areas shown is to give total quantities, while the irregularity of the outlines serves to accentuate the periods and amounts of production at the different stages of the experiment. An added feature of helpfulness in this diagram is the superimpos-

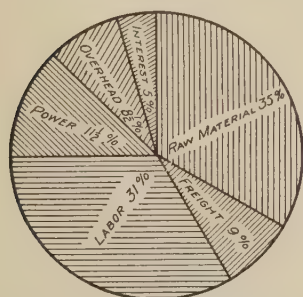


FIG. 17. Sector diagram.

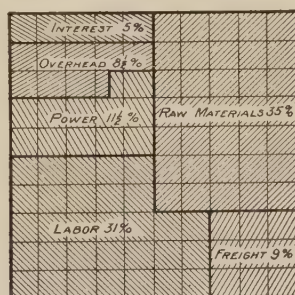


FIG. 18. Distribution area diagram.

ing of the outline of the production area of the first half of the diagram on the corresponding area of the second half.

Still another form of area diagram, which is worth mentioning, is the miniature life diagram represented in Fig. 20,\* in which certain facts concerning persons or things are set forth by various miniature drawings of the things themselves, and in which the sizes

\* Taken from *Graphic Methods for Presenting Facts*, page 51, 1914 edition, by W. C. Brinton.

of the drawings depict the corresponding sizes of the things represented. The facts presented are thus vitalized and vivified and thereby become permanently fixed in the mind. The skill of the

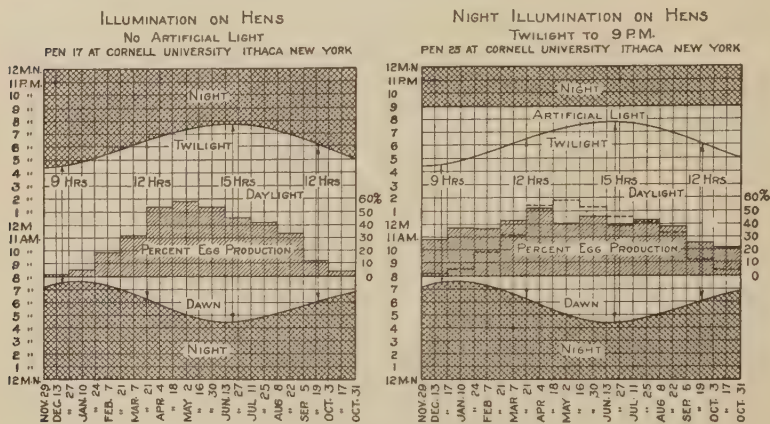


FIG 19. An effective area diagram.

draftsman in pictorial drawing is brought into effective use in this kind of graphical representation.

Volume diagrams should seldom be used. If, however, the idea

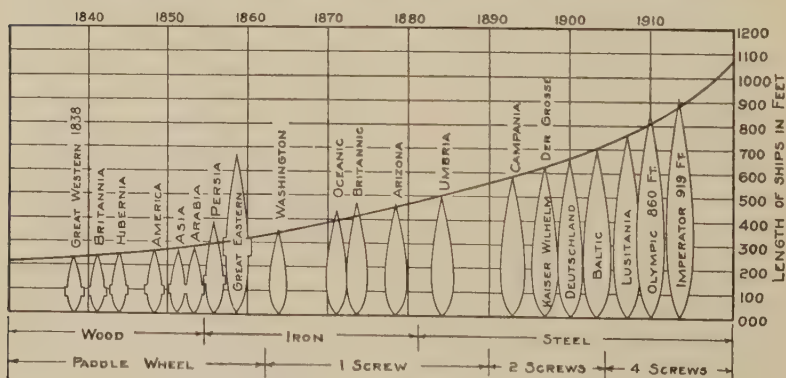


FIG. 20. Picture barograph and plane curve.

of bulk and mass is paramount in the comparison, a suitable volume diagram done in isometric or oblique projection is justified. The mass of an iceberg compared with that of a ship might very well be represented by two cubes.



The chief objection to area and volume diagrams lies in the fact that in the hands of most persons they are incorrectly used and constitute a source of misinformation. Such an instance occurs in the use of triangles to compare quantities, in which the effect of areas enters into the comparison, while in fact only the heights of the triangles represent the real state of things. Always the comparison of areas inadvertently takes place in the mind of the observer and, except in very limited cases previously mentioned, such comparisons are faulty. In the same way, improper use of volumes, such as cylinders, is made when only heights of the cylinders give the true conditions. If all dimensions except heights are kept constant, then such diagrams are no more than barographs and should be replaced by the latter.

In line, area, and volume diagrams, as in plane curve diagrams, a sufficient amount of descriptive material to make the meaning of each part clear should be placed on the diagram proper in the form of base-line scales, notes, legends, and titles. A simple, clear style of lettering is imperative on all diagrams of this character, since they are intended for popular use and must be easy to read. The general laws of technique in drafting, hitherto explained, are applicable to these types of diagrams.

**MAP AND DISTRIBUTION DIAGRAMS.** — This type of graphical representation is very useful in presenting facts and statistics which have a geographical or place significance or which show distribution of authority and effort. The latter type of diagram includes the commonly used organization chart, the so-called rank charts, and many others of a similar nature. Figures 21 and 22 represent these types of charts and diagrams very well. The salient features of each are at once evident and need not be elaborated. It is important to point out, however, that in addition to the element of place, which is always present in map diagrams, the effect of quantity can also be readily added, as is done in Fig. 21.

The draftsman is given opportunity to display his ingenuity and creativeness in these forms of chart and diagram drawing, quite as much as in any other drawing. The numerous devices for indicating the quality of material or shape of the things represented on such a distribution diagram are often very clever and instructive.

**GRAPHIC STATICS AND VECTOR DIAGRAMS.** — Graphic statics diagrams are used to determine stresses directly, or to check the analytical computation of stresses in members of trusses or other structures under load. The construction of such diagrams presup-



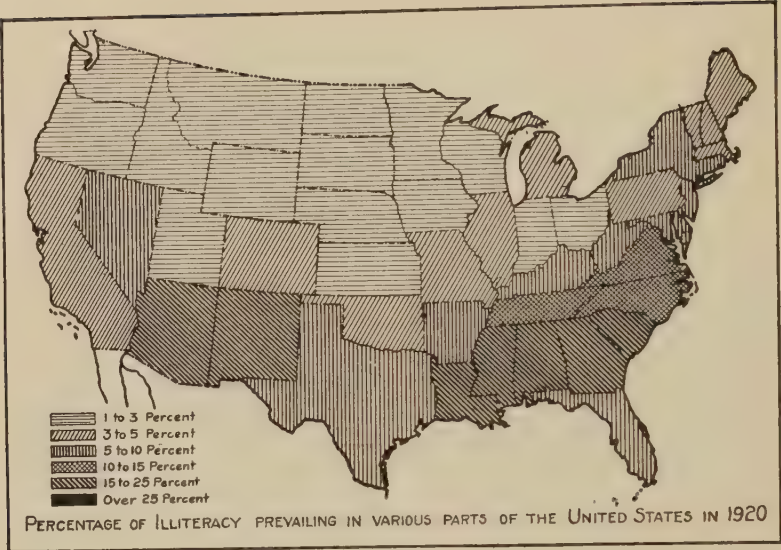


FIG. 21. Distribution map.

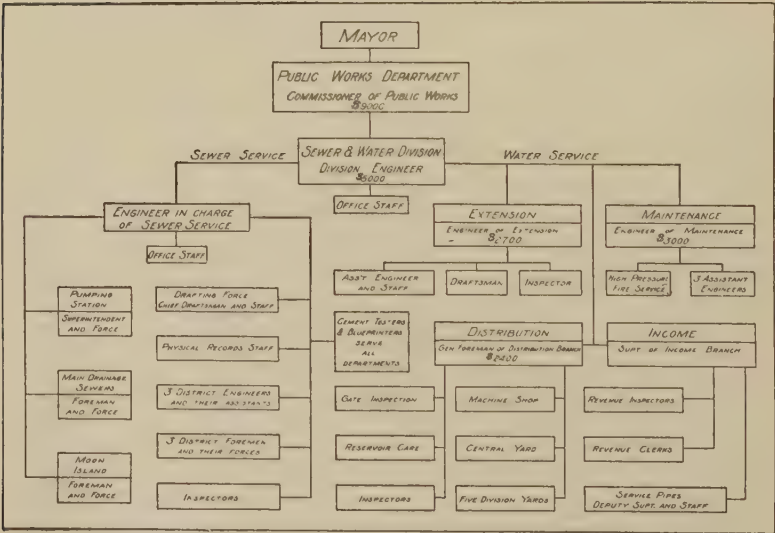


FIG. 22. Organization chart.

poses a thorough knowledge of the representation of forces by vector quantities, that is, by the lengths and directions of straight lines. Further, the construction depends upon an understanding of stress analyses of structures, which is, in turn, dependent upon analytical mechanics. Figure 23 shows such a diagram; it need only be pointed out that the length of each line in the diagram and its direction corresponds respectively to the size and direction of the

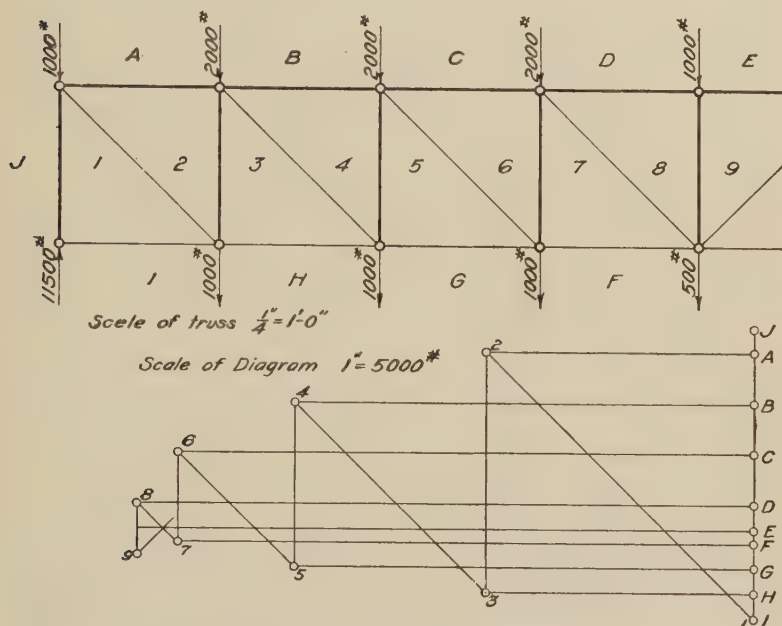


FIG. 23. Graphic statics diagram.

stress in the truss member which the line represents. Vector diagrams in any field are based upon similar considerations of direction and magnitude and need not be elaborated here.

The drawing problems involved in the construction of such diagrams are few, and consist chiefly of accurate scaling and layout of parallel lines.

**NOMOGRAPHS.** — The subject of Nomography is of especial interest to engineers, scientists, and others who are constantly dealing with problems involving the repeated solution of algebraic equations. Because of the simplicity of manipulation of a nomograph, which, after its construction, eliminates the laborious process of re-

peated substitution in, and solution of, a complicated formula, it should continue to find wider and wider use among engineers.

Briefly, a nomograph is simply a set of vertical scales, or a set of inclined and vertical scales, which are so spaced and arranged on a chart that they represent the various elements of a formula (Nomogram) in a graphical way. Any unknown value in the formula can be found by simply laying a straight edge across the scales, either once or several times, and reading the correct result from the proper scale. Known values in the formula are cut on the proper scales by the straight edge, while the unknown values can be read from other scales at points where the straight edge cuts them in the suc-

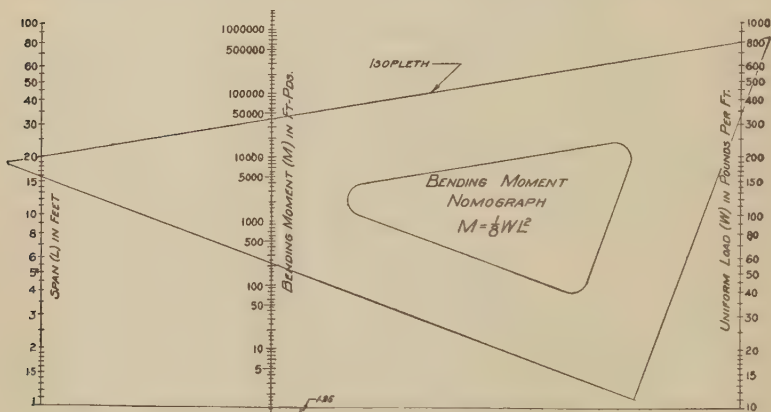


FIG. 24. Nomograph — computation chart.

cessive applications of it to the diagram. The straight edge when so used is called an *isopleth* which means “corresponding values of the variables of an equation.”

Figure 24 shows a simple nomograph and the method of using it. It will be noted that each scale is marked, to correspond with the variables in the nomogram, either with the symbol itself or the thing the symbol stands for. The scales are all vertical. Every variable in a formula must be represented by a scale in the nomograph, which may be in decimal or logarithmic units, depending upon the nature of the equation. Figure 25 shows the data used in Fig. 24 plotted on the ordinary coördinate paper. A comparison of the two figures serves to show more vividly the advantages of the nomograph, which were mentioned above. Because of the almost

exclusive use of straight lines in nomographs, they are often called "straight line diagrams" or "alignment diagrams."

The only drafting skill required in the preparation of a nomograph is that of careful measurement in the layout of the various

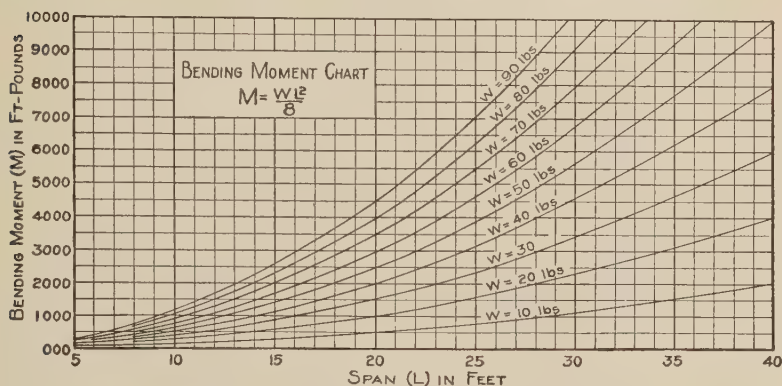


FIG. 25. Plane curves — computation chart.

scales and their subdivision into correct units of value. Heavy, non-expanding paper or board should be used for such diagrams.

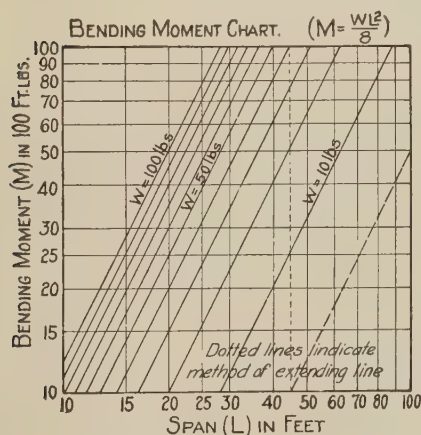


FIG. 26. Logarithmic chart.

Another very convenient method of presenting the graphs of equations to be used for computation purposes is shown in Fig. 26. The same data shown in Fig. 25 are here shown on logarithmic paper. It will be noted that the graphs have become straight lines, as is always the case with any equation of the form  $y = mx^a$ .

In a very real sense, we may say that the slide rule and many other sliding or rotating devices for computation work are based on the principles of the nomograph.

**THREE-DIMENSIONAL CHARTS.** — Figure 27 shows a typical three-dimensional chart and the mathematical formula used in

deriving the values which are plotted on each coordinate axis. It

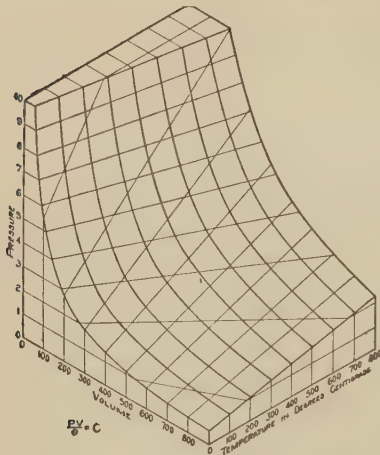


FIG. 27. Three-dimensional chart.

will be noted that the drawing is simply an isometric in which the various points are determined by values derived from a formula of three variables.

The smooth surface formed by the points and interpolations between points is of very great value in demonstration work, especially in connection with the study of laws governing the expansion of gases. Such a diagram is a good substitute for the more expensive models sometimes used.

Figure 28 illustrates a variation of the three-dimensional chart which is often used in statistical work. The figures are self-explanatory as far as the drafting problems are concerned.

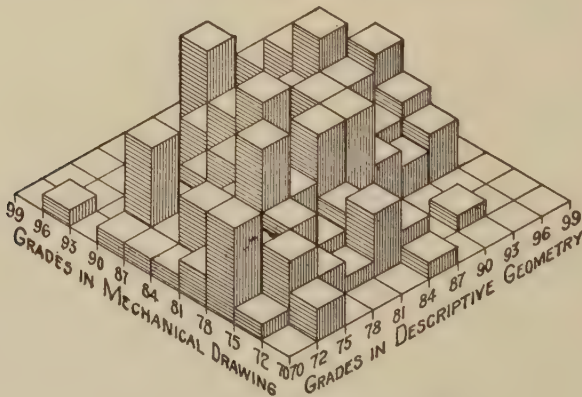


FIG. 28. Three-dimensional chart.

#### BIBLIOGRAPHY

- GRAPHIC METHODS FOR PRESENTING FACTS, by W. C. Brinton. The Engineering Magazine Co., 1919.
- GRAPHICAL METHODS, by W. C. Marshall. McGraw-Hill Book Co., 1921.
- HOW TO MAKE AND USE GRAPHIC CHARTS, by A. C. Haskell. Codex Book Co., 1919.
- GRAPHICAL AND MECHANICAL COMPUTATION, by Joseph Lipka. John Wiley and Sons, Inc., 1918.
- THE CONSTRUCTION OF GRAPHICAL CHARTS, by J. B. Peddle. McGraw-Hill Book Co., 1910.



## CHAPTER XVIII

### MAP DRAWING

A map is a representation of a portion of the earth's surface showing all of the important features, or only those of one class, e. g., only rivers, lakes, and mountains. From the practical point of view, and when the area to be shown is small, a map is a one-plane orthographic projection, involving the use of mechanical drawing, freehand drawing, and lettering. When the area to be shown is so large that the curvature of the earth's surface must be taken into consideration, some other method of projection must be used. Thus, projections may be made on the inside of cylinders or cones imagined to be tangent to the earth's surface. When the cylinder is developed according to the rules of Descriptive Geometry, the meridians and parallels of latitude appear as straight lines; in the case of the cone, the parallels of latitude appear as circles while the meridians may appear as convergent straight lines or as curves, depending upon the method used. When a series of cones are used, the map is called a polyconic projection. The cylinder projection, with some modifications, is called a Mercator's projection. Further information concerning these types of projection may be found by consulting some of the works listed in the bibliography at the end of this chapter. Articles on relief maps and mapping by photography are also included in most of the treatises.

**CLASSIFICATION OF MAPS.** — Maps may be classified according to their scale, the character of the things shown — whether real or imaginary, the method of projection, or the purposes for which they are to be used. On the basis of their purpose, Professor E. R. Stuart divides maps<sup>1</sup> into four classes, which he calls *geographic*, *topographic*, *cadastral*, and *engineering*. While no hard and fast lines can be drawn between the various classes of maps, the distinctions are usually quite clear, as may be noted from the descriptions in the following paragraphs.

**Geographic Maps.** — Maps of this group show a comparatively large area, and must therefore be drawn to very small scales, which

<sup>1</sup> Topographical Drawing, by Edwin R. Stuart, U. S. Military Academy.

means, of course, that only the more important features of the earth's surface can be shown, such as the larger rivers and lakes, mountains, cities, railroads, etc. On these maps the cities are located by small circles, and only the larger curves in streams and the principal changes of direction of the railroads are shown. Examples of such maps are to be found in any atlas or geography textbook, and hence are familiar to everyone. The scales vary from a few miles to the inch to several hundred miles to the inch. Relief, or difference of elevation, is shown in a very general way, usually by hachures or shading, or it may not be shown at all.

**Topographic Maps.** — Much smaller areas are shown in maps of this class, and hence they may contain considerably more detail. Just how much detail may be shown on them will, of course, depend upon the scale. Topographic maps prepared by the United States Geological Survey are made to a scale of approximately one inch to the mile in the thickly settled industrial districts, and to a scale of nearly one inch to four miles in the desert regions of the West. The large-scale maps show all natural features down to the little streams which run dry in the summer. Civil boundaries, city streets, country roads, tunnels, aqueducts, bridges, houses, and all the works of man of a permanent nature, are shown, together with permanent vegetation, such as forest areas. A portion of a topographic map is shown in Fig. 1. Elevations are shown in a definite manner by the use of contour lines. Topographic maps are frequently made to scales ranging up to 6 inches or more to the mile. The term "topographic" is sometimes applied to maps which include only a few of the features mentioned above.

**Cadastral Maps.** — Maps of this class are used primarily for showing political and civil boundaries, together with property lines, and are used for the purposes of taxation and the transfer of property. Hence, because of the accuracy required, such maps must be drawn on a still larger scale than either of the preceding classes. They contain, besides the property lines, only enough of the natural features, such as streams and roads, to enable one to locate the corresponding lines on the ground. Plats of city additions, mineral rights, farm surveys, and the like fall in this group. A small portion of a city plat is shown in Fig. 2. The scale for such maps is usually greater than 6 inches to one mile.

**Engineering Maps.** — Maps drawn for reconnaissance, construction, or maintenance purposes are called engineering maps. The scale is seldom smaller than 1 inch equals 400 feet, and it may ap-

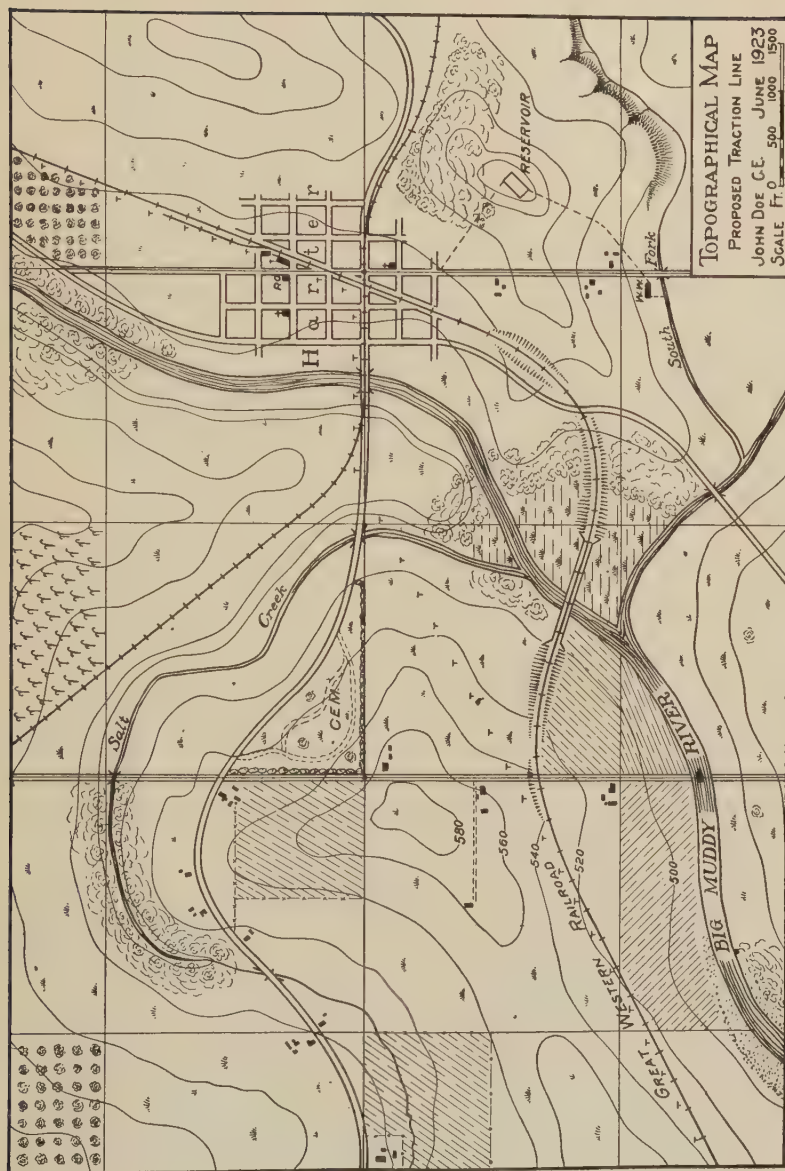


FIG. 1. Topographic map.

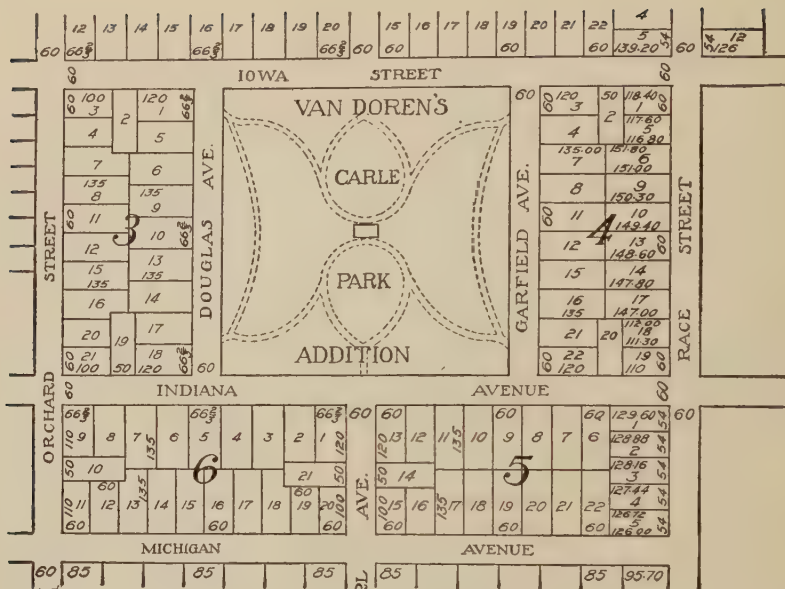


FIG. 2. City plat, cadastral map.

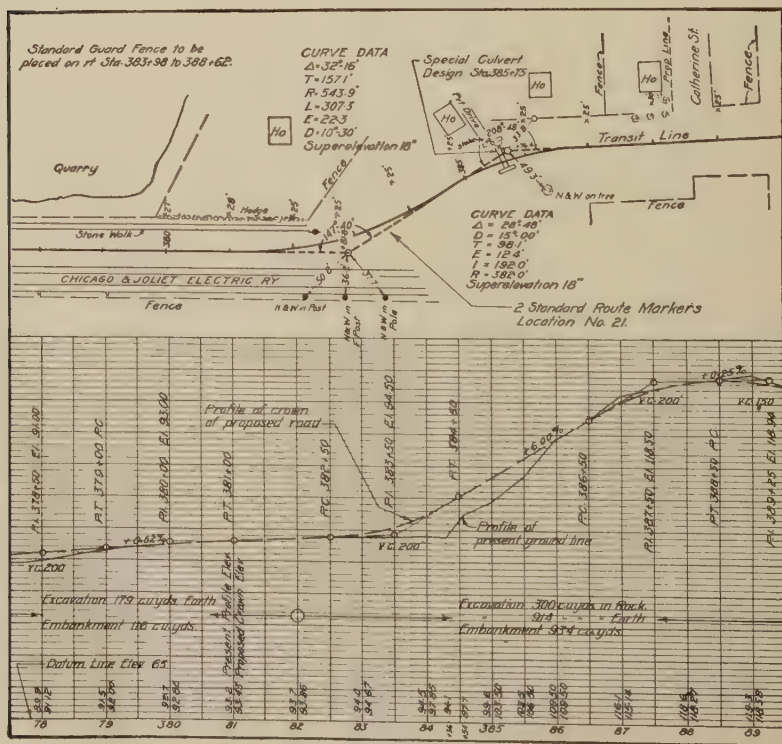


FIG. 3. Highway map.



proach the architectural scales as the other limit. Maps for railroad, highway, canal, or hydro-electric construction are excellent examples of this class of maps. Such maps frequently have the character of topographic maps in that they include practically all of the natural features, vegetation, and works of man. Being on a larger scale, they are, of course, much more accurate in detail than the usual topographic map. A portion of a highway construction map is shown in Fig. 3, and a railroad station map in Fig. 4.

Still other classifications might be made; but in most cases further distinctions are in reality but subdivisions of one of the four classes given above. Thus, military maps are really general topographic maps with certain features emphasized, while hydrographic maps are engineering maps applied in particular to water development purposes. Contour maps, showing only elevations, are engineering maps and are usually employed for location purposes.

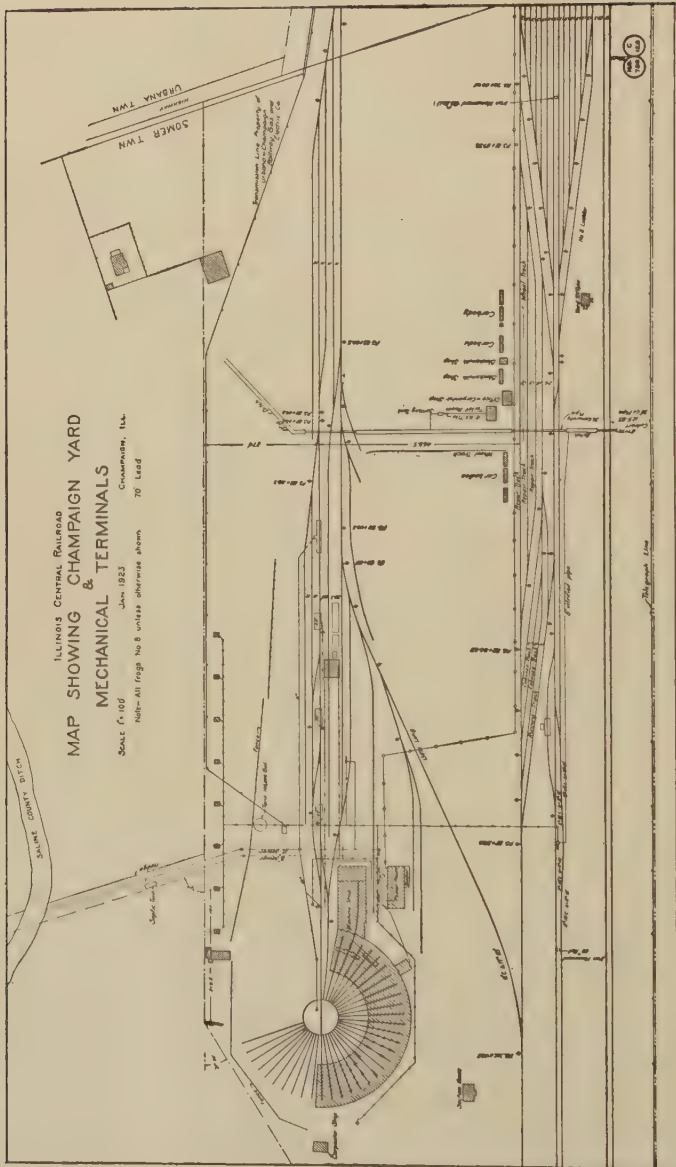
**SCALES.** — In the foregoing classification of maps, it will be noted that there are scales ranging from one-tenth of an inch equals 1 foot, to 1 inch equals 200 miles. With such a wide range, it is quite evident that the proper choice of a scale will involve several factors. Among these, four stand out above the others.

**Area and Form.** — The size of the area to be shown is, of course, the first factor. The larger the area shown the smaller must be the scale, to keep the map within workable drafting limits. The form in which the map is to be used must be taken into account. If it is to be used in a book or atlas, not only will it have to be quite small, but the original must be of such size that it can be reduced photographically to the final form without blurring or loss of detail. If, on the other hand, the map is to be made as a tracing and used in blueprint form, its size is limited only by the tracing cloth.

**Purpose.** — The purpose for which a map is to be used must also be considered. Thus, a map to be used in highway construction must be made to a much larger scale than a map showing a proposed highway system for a bond issue. On the construction map, all the curves, culverts, bridges, cuts, and fills must be shown very clearly, to enable contractors to make accurate estimates, while on the other, only the general route from city to city is of interest.

**Length of Service.** — Another item to be thought of, though usually not so important, is the length of time the map will be in service without revision. The larger the scale the sooner the map will be out of date, for many of the details shown on a large-scale





By permission of Illinois Central Railroad Company.  
Fig. 4. Railway yard and terminal map.

map may be changed within a short time, whereas on a small-scale map these details must be omitted and hence changes in them do not affect its accuracy. The larger features shown on a small-scale map are not so apt to be changed in short intervals of time.

**Cost.** — Cost of making a map is the most vital factor in its preparation. If the scale is to be large, more information is shown, and hence the cost is correspondingly high, since it requires more labor both to get the information and to reproduce it on the map.

The scale of a map is usually shown graphically at a place near the title, and the scale ratio is also given in terms of feet or miles to the inch. When a ratio is given, it is stated entirely in terms of inches. Thus a scale of 1 inch to the mile is expressed as 1:63360. United States Government maps are made on scales of 1:62500, or 1:125000, or 1:250000. The largest of these scales is almost 1 mile to the inch, and the smallest practically 4 miles to the inch.

All survey measurements are made in feet and decimals of feet, instead of feet and inches; hence, the engineer's scales on the box-wood rules are in the decimal system, and we have 10, 20, etc., divisions to the inch. These units may represent 10, 20, 30, etc., feet to the inch, or 1, 2, or 300 feet to the inch. The smallest subdivisions on an engineer's scale are 60 to the inch, and a draftsman can draw with reasonable accuracy to this scale. On a map drawn 1 inch to the mile, these smallest divisions would represent 88 feet, so that representations of any kind must be approximations at best. To represent a railroad or a highway by even a single line would be an exaggeration of scale. On a 6-inch map, that is, one to a scale of 6 inches to the mile, one of the small divisions on the engineer's scale would represent about 14.7 feet, which permits of greater accuracy in location and makes a closer approximation to scale sizes possible. But even with this scale, most symbols are still an exaggeration.

**SYMBOLS.** — Since the scale of all maps is small, relatively speaking, the representation of objects upon them must be highly conventionalized. Upon all maps, regardless of the scale, even the largest objects must be shown by a symbol rather than by top view. For the purpose of the map is, after all, not to show the exact appearance from above, but rather to show the size of objects and their position relative to each other. Hence, conventional signs and symbols have been devised which bear some resemblance, where possible, to the object itself. The purpose of having this resem-

blance is for convenience in interpretation, and, of course, it cannot be carried too far in a conventionalized system.

A well-standardized system of symbols, used by all the map-making departments of the Government, is published in a small booklet, called *Conventional Signs*, War Department Document No. 418. The sizes of the symbols shown in this booklet are for maps made to a scale of one inch to the mile.

**Size and Prominence.** — The size of symbols should vary only slightly with the scale of the map, since, to almost any scale, most symbols are exaggerations no matter how small they are made. Further, since the symbols are largely freehand work, this variation in size must be a matter of judgment. The symbols shown in this text, in the appendix, are the proper size for a six inch scale map. This is about the maximum size for use on any map, because larger symbols, especially those of vegetation, would seem clumsy and, in general, attract too much attention.

The size of a symbol is, of course, one of the factors in determining its prominence, but this effect can be modified very largely by the weight of the lines used in making it. Since the variation in the size of symbols is quite limited, and is definitely related to the scale of the map, prominence must be secured largely by the weight of line. The purpose of the map will determine, to a large extent, which symbols are to be made most prominent. On a road map, for example, the road itself should be most prominent, and all features directly connected with it, such as bridges, culverts, etc., should be of equal weight. On an oil property map, flowing wells, dry wells, railroads and roads, and property lines are the important features. In practically all cases, the vegetation symbols are least important and, therefore, should be drawn lightly and not too close together. Each symbol has a definite form, just as each letter in the alphabet has a definite form. Skill in making the symbols can only be acquired by careful, thoughtful practice. Careless and hasty drawing must be condemned as worse than useless.

**How to Draw Symbols.** — There are two distinct steps in learning how to draw symbols, the first of which is a careful examination of a correct model or sample of the symbol, and the second, an endeavor to reproduce it. The most important of these steps is the examination of the sample, for upon the keenness and accuracy of the observation depends the effort at reproduction. For example, an examination of the water lining at the right in Fig. 5 will make clear that the first lines are drawn very near to the shoreline and

follow it around very closely, while the lines become farther apart and less irregular as we approach the center of the body of water. Examples of both correct and incorrect water lining are shown in Fig. 5.

Similarly, a careful examination of the symbol for grass in Fig. 6 will show that it consists of about seven short strokes, ranging in length from almost a dot at the ends to about three thirty-seconds of an inch at the center. It will also be observed that these strokes are slightly curved and seem to meet in a common center. The individual symbols are arranged at random and not in rows. The careless observer would fail to note many of these essential points, and consequently his attempts at imitation would lack the things which he overlooked. Common errors in making the symbol for

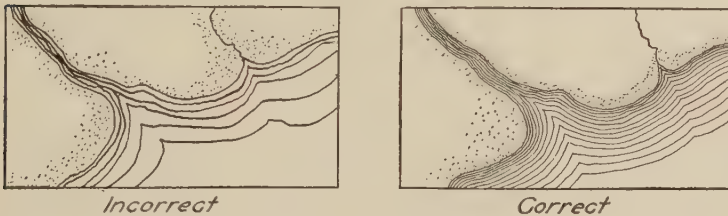


FIG. 5. Water lining.

grass are shown in Fig. 6 in contrast with a correct execution. Likewise, the result of poor observation of the tree symbol is shown in Fig. 7.

**Colors of Symbols.** — On a finished map, the symbols should be shown in colors. The colors for each symbol are indicated in the Chart of Topographic Symbols, in the Appendix. These colors may be readily remembered by four simple groupings, thus: the artificial features, or works of man, are made in black; water features in blue; contours, sand, washes, etc., in brown; and vegetation in green. In printing maps, each color requires a separate printing; therefore a reduction in the number of colors used reduces the cost. Since vegetation is not permanent except in the case of very large forests, the green is usually omitted.

**Spacing of Symbols.** — One of the greatest difficulties in drawing symbols is to learn how to space them. The general tendency is to cover the sheet too thickly. The draftsman must constantly be on his guard against this practice, for two reasons. First, the more symbols drawn the longer it takes and the more it costs to produce



the map. Second, it is more difficult to produce uniformity of texture when the symbols are crowded. The occurrence of heavy and light areas on the map are disagreeably noticeable when symbols are placed too close together. When there are large areas to be covered with symbols involving the use of parallel lines, as for example in the case of marsh lands, a section liner should be used.

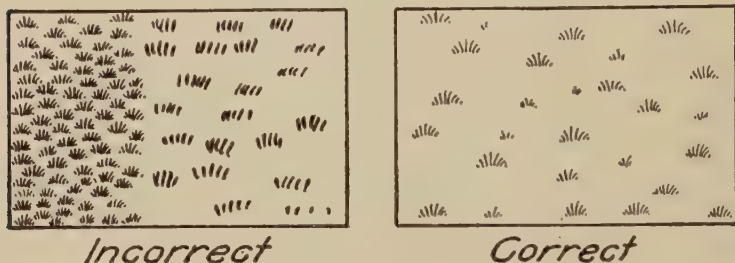
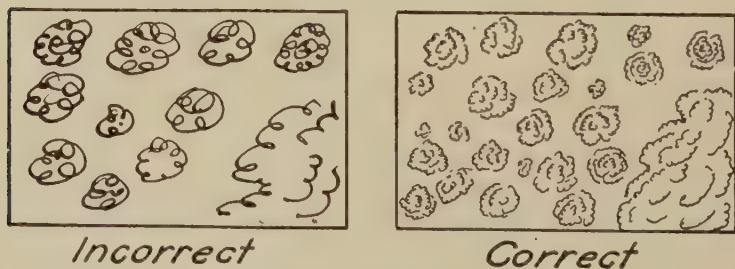


FIG. 6. Symbols for grass.

**Position of Symbols.** — Another very important point is the position of the symbols on the sheet. All symbols which have a definite base, as for example, grass, marsh, palm trees, corn, etc., should be drawn with the base parallel to the bottom of the sheet, so that the symbols appear in a natural upright position. They should never be placed with their bases parallel to roadways or



7. Symbols for round leaf trees.

property lines which run diagonally across the sheet. An illustration of this point is shown in Fig. 8. Symbols for vegetation which occurs in rows, however, may have the rows running in any direction.

**SPECIAL SYMBOLS.** — For some purposes, special symbols must be devised. Thus, for purposes of aerial navigation, a map must show clearly those objects which project up into the air and may be



obstructions to flight. A page of these symbols is shown in the Appendix. Such objects as roads, railroads, railway stations, rivers, lakes, woods, telegraph lines, and the like, which will not interfere with flight, are shown by the usual symbols.

Property maps of various industries may also require the engineer to devise symbols to show certain features which are not included among the standard symbols. It should be the engineer's purpose to make such symbols always unmistakable as to meaning and easy to interpret.

**PLOTTING A MAP TRAVERSE.** — The method of plotting map notes depends upon the method of making the survey and upon the

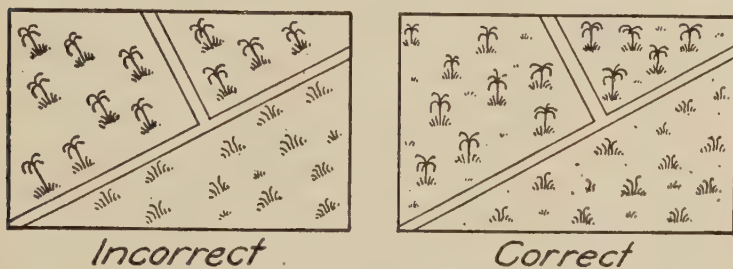


FIG. 8. Symbols for palm trees.

accuracy required. In general, the plotting on a map indicates or duplicates in miniature the work carried out in the field. Thus, an angle measured in the field with a transit may be measured on the map with a protractor, and a distance measured by tape or stadia in the field is measured on the map with a scale.

The three most common methods of plotting transit surveys, in an ascending order of accuracy, are:

1. Protractor and Scale Method; 2. Tangent Method; and
3. Rectangular Coördinate Method.

**Protractor and Scale Method.** — Where great accuracy is not required, the survey notes may be plotted by means of the protractor and scale. The degree of accuracy depends both upon the kind of instruments used and upon the skill of the draftsman. Any errors made are, of course, carried forward, but are not necessarily cumulative, since the possibility of error in either direction is the same, and in a large number of measurements these errors will to some extent balance each other, unless the errors are due to a personal and constant tendency of the draftsman to overestimate or to underestimate in plotting angles or distances.

For ordinary work, nothing less than a 6-inch celluloid protractor should be used, and this should be tested to see that the 180- and 90-degree angles, at least, are correct. Steel protractors, with straight edge and vernier attached, are of course much more desirable.

A portion of a page of survey notes is shown in Fig. 9. Let it be

|                                       |  |  |                  |             |
|---------------------------------------|--|--|------------------|-------------|
| <i>☒ of R.R. bridge</i>               |  |  | <i>79°-40'L</i>  | <i>603'</i> |
| <i>☒ of Park road bridge</i>          |  |  | <i>138°-50'L</i> | <i>231'</i> |
| <i>Shore of island at fork</i>        |  |  | <i>171°-20'L</i> | <i>220'</i> |
| <i>03</i>                             |  |  | <i>59°-40'R</i>  | <i>652'</i> |
| <i>☒ of Park road No. 1. on Curve</i> |  |  | <i>151°-45'R</i> | <i>119'</i> |
| <i>North corner of boat house</i>     |  |  | <i>121°-25'R</i> | <i>575'</i> |
| <i>02</i>                             |  |  |                  |             |

FIG. 9. Survey notes.

required to lay out the angle at Sta. 2 to locate Sta. 3 from these notes. Assume the point *B* in Fig. 10 to be Sta. 2 and the line

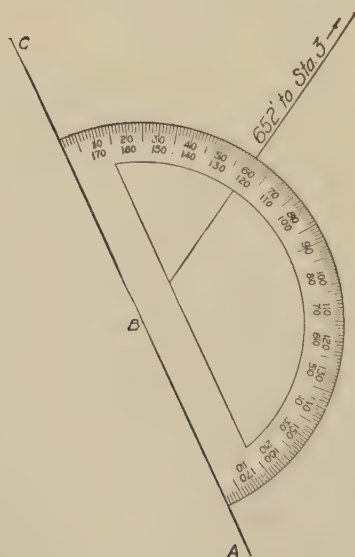


FIG. 10. Angles by protractor method.

*BA* the "backsight." The first step, then, in laying out the angle is to extend the line *AB* so far past *B* that both ends of the protractor may be on the line when the center is at *B*. Deflection angles are measured to the right and left of the sight line produced; that is, a deflection angle marked right should be laid off to the right of the extended line *AB* when looking forward along that line in the direction *C*. Hence, the protractor must be laid on the right or left side of the line from which the angle is measured, according as the notes describe

it as right or left. Having the protractor set as described above, mark off the angle of  $59^{\circ}-40'$  as accurately as possible, with a

very sharp pencil. With a straight edge and pencil, draw the line through the point *B* and the new point just located, and on this line scale off the proper length, namely, 652 feet.

**Tangent Method.** — This method is more accurate for the plotting of angles, but requires more time; hence, it is generally used for plotting traverses, while the protractor method may be used for plotting in the details. The tangent method requires a table of natural tangents and is, in brief, simply the plotting of an angle on the basis of the definition of the tangent. Again assuming the same angle as in the previous case, draw the line *AB*, see Fig. 11, and extend it beyond *B* and lay off on it ten units with any one of the engineer's scales. The larger the scale the greater the accuracy.

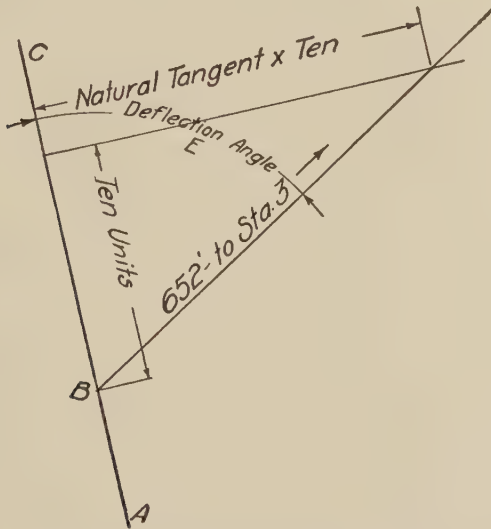


FIG. 11. Angles by tangent method.

At the end of these ten units, erect a perpendicular to the right of the line, since the deflection is marked right, and on it scale off the natural tangent of the angle multiplied by ten, which is 1.6429. Then through the point thus located and the point *B* draw the line required and on it scale off the distance 652 feet.

If the deflection angle is much greater than 45 degrees, greater accuracy may be obtained by first erecting a perpendicular at *B* and laying off on it ten units, and then at the end of this ten-unit line erecting another perpendicular on which may be laid off a

distance equal to ten times the tangent of the complement of the angle as shown in Fig. 12.

If the deflection angle is greater than 90 degrees, the ten-unit

line must be laid off between *B* and *A*, as shown in Fig. 13, and the tangent of the supplementary angle must be used.

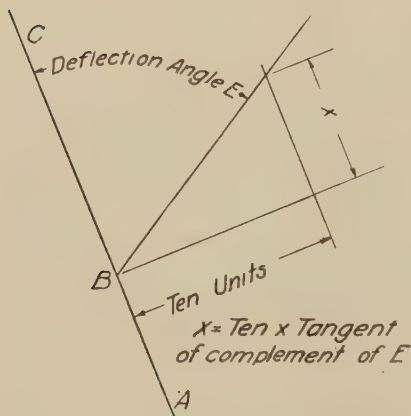


FIG. 12. Angles by tangent method.

**Rectangular Coördinate Method.** — Inasmuch as this method requires considerable trigonometric calculation and is used only when great accuracy is required, it will not be discussed in this text. Complete information concerning this method may be found in surveying texts.

**REPRESENTATION OF ELEVATION.** — A one-plane projection can show only two dimensions, but for many purposes it is highly

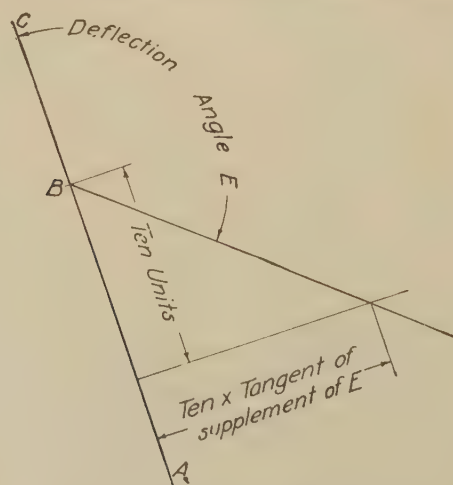


FIG. 13. Angles by tangent method.

desirable that a map shall show three dimensions, namely; length, breadth, and difference of elevation. This object may be attained

by two conventional schemes, that is, by the use of hachures or contours.

**Hachures.** — If only a general idea of the elevation of the country is desired, the method of hachures is satisfactory, since it gives the effect of relief and is readily understood by the average person. Differences of elevation between any two points, however, can only be shown in a very relative manner. An example of this method of representation is shown in Fig. 14, from an examination of which it will be noted that the strokes are short, heavy, and close together where the slope is steep, becoming gradually longer, lighter,



FIG. 14. Hachures.

and farther apart as the slope becomes more gentle and approaches the horizontal. The direction of the stroke should be the same as that in which water would flow on the slope. Care should be exercised not to have a continuous white line between the several rows of short strokes.

**Contour Lines.** — A contour line on a map is the projection of an imaginary line on the earth's surface which passes through all points of the same elevation. The meaning of a contour line may perhaps become a little clearer from an examination of Fig. 15, the lower part of which shows a landscape in perspective, and the upper part of which shows the same landscape in map form with elevations indicated by contour lines at intervals of 20 feet. The shoreline is in reality a contour line. The first contour line above the shore represents what the shoreline would be if the water rose vertically 20 feet. To put it in other words, if a man could walk along such a line on the ground, he would go neither up nor down but



proceed always on a level and eventually he would return to the place from which he started.

With a little reflection the following rules will be observed to be true, both of imaginary contour lines on the ground and of their projection on a map. The rules are stated as applied to a map.

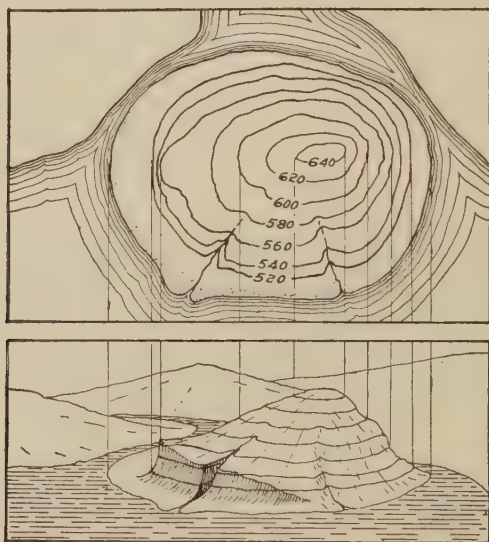


FIG. 15. Contours.

1. Every contour line must either close upon itself or extend to the edge of the map.

2. When a contour line closes, it usually indicates a summit but it may indicate a depression. When it indicates a depression, this is made clear by the symbol shown in Fig. 16.

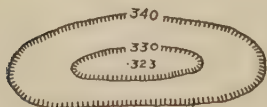


FIG. 16. Depression contours.

3. Contour lines never cross.

4. Where contour lines are close together the surface is steep, and where they are far apart the surface is gently sloping.

5. When contour lines are close together, they are in a sense parallel to each other (not parallel in a strictly mathematical sense). When they are far apart they need not necessarily be parallel.

6. Contour lines approaching a stream go upstream before reaching the water's edge, where they stop at points directly opposite

each other at right angles to the stream. If the stream is shown by a single line they cross it at right angles; if shown by two lines, they do not cross.

7. Contour lines cannot run into the shore of a lake or other still body of water, since the water surface is at the same level at all points.

8. The first contour lines from the water's edge, on opposite sides of a still body of water, must be of the same number or elevation.

9. It is customary to make every fifth contour line heavier than the rest. This line is broken at some convenient place, and the number representing its elevation is inserted in the break in the same color of ink as the line. Where the contour lines are far apart, each one may be numbered.

The numbers indicating the elevation of the contour lines are lettered parallel to the contour line, and, where possible, the numbers for consecutive lines are placed in rows, as shown in Fig. 16. When it is possible, these numbers should read from the bottom of the sheet. Contour lines may be drawn with a lettering pen or with a pen designed especially for the purpose and called a contour pen. See Fig. 17. The point of this pen is on a swivel which allows it to turn freely in any direction.

The contour interval may be any desired value, from 1 foot in very flat country up to 200 feet in rough mountainous country. By contour interval is meant the vertical distance between the planes of consecutive contour lines. Five, 10, 20, 100, and 200 feet are the intervals most frequently used.

On a summit or depression, the last contour line is numbered, or the elevation of the high or low point within the contour is given.

**PROFILES.** — A profile is a line, usually drawn on coördinate paper, showing the elevations of the ground along some one particular line on the earth's surface. While a profile represents something entirely different from a contour, yet the two are related in such a manner that one may be obtained from the other. A profile usually accompanies a map showing a road, railroad, sewer, water supply line, or canal location. If the profile is to be made very



FIG. 17.  
Contour pen.

accurately, the elevation of points on the line should be obtained by means of a level in the field. However, a profile for preliminary purposes may be obtained from a contour map.

When elevations are obtained with an instrument in the field, readings are taken every 100 feet in flat country, and at closer intervals of 50, 25, or 10 feet in rough country, depending upon the ruggedness of the slope. These readings are then plotted on a special coördinate paper called profile paper, in which the spacing of coördinates is different in the two directions.

When the elevations are obtained from a contour map, the proposed line is drawn on the map and the intersections of this line

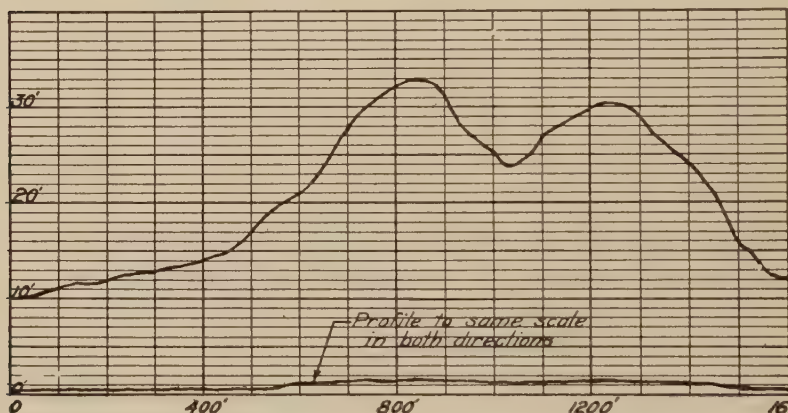


FIG. 18. Profile, two scales.

with the contour give the elevations of points whose distances apart are obtained by scaling the map. These points are then plotted on the profile paper.

Profiles, as indicated in a preceding paragraph, are usually plotted to two different scales, the larger of which is used on the vertical axis. The purpose of the two scales is to show the variations of elevation more clearly. Since a profile is usually thousands of feet or several miles in length, while the difference of elevation varies only over a few hundred feet, it is quite evident, therefore, that a scale which would bring the horizontal length within workable limits, when applied to the vertical distances, would make them so small as to be insignificant. Figure 18 shows a profile plotted, first, to the same scale in both directions, and second, to two different scales. From an observation of these figures it is quite clear that the second scheme is the only one of practical value.

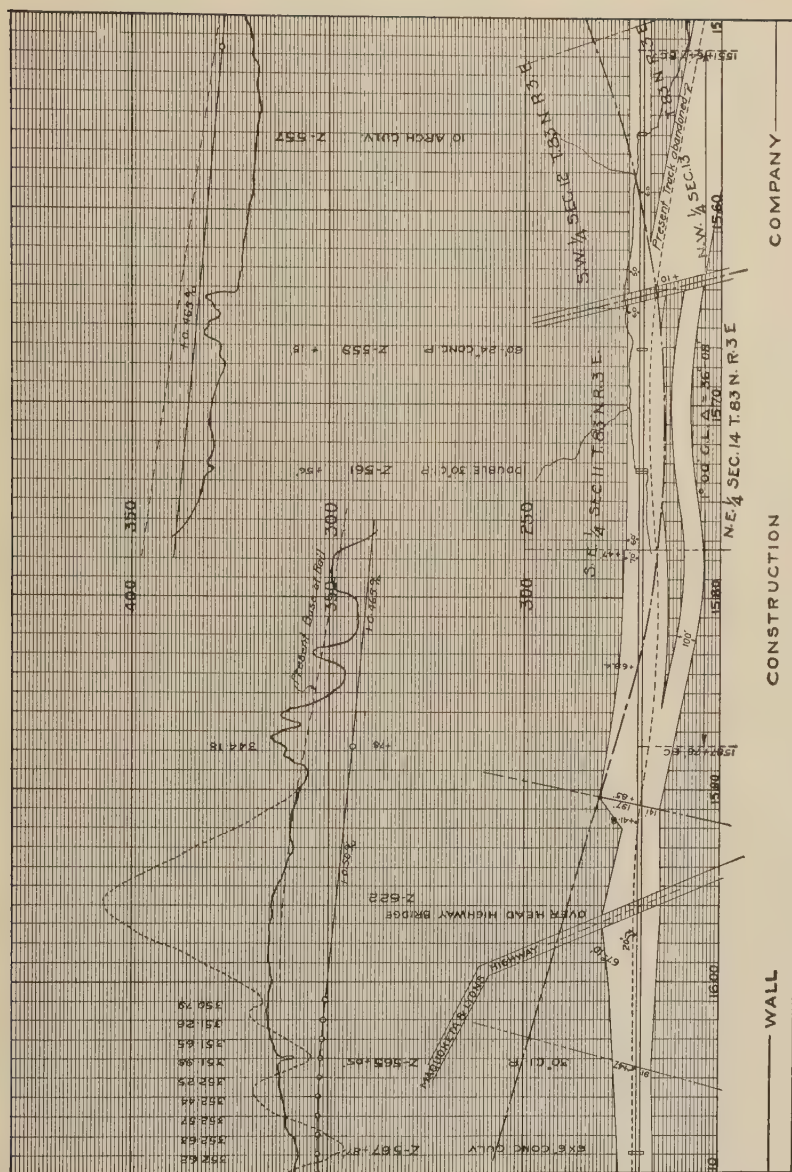


FIG. 19. Railway profile.



**Profile on Curves.** — When a profile is made of a line, a portion of which is curved, like a railroad line, for example, the developed length of the curve is shown in profile and not the projected length. In other words, the length of the profile is the same as the true length of the line. The beginning and ending of the curve is shown, and the degree of curvature is indicated, as in Fig. 19.

**Profile Papers.** — Profile paper is furnished to the trade in three standard rulings, 4 and 20, 4 and 30, and 5 and 25 lines to the inch. It is prepared in 220 and 50 yard rolls, 9, 10, and 20 inches wide, but it may also be obtained in sheets measuring 15 by 42 inches. The sheets are printed on drawing paper only, but the rolls may be had in drawing paper, tracing paper, tracing cloth, or paper mounted on muslin. There is also a paper called plan profile paper. It comes in 20-inch widths but only one-half the width is printed, the other half being left blank for plans and sketches. This kind of paper is used in highway work.

**LETTERING.** — Engineering maps, particularly those drawn to a large scale for the purpose of construction, are usually lettered in

A B C D E F G H I J K  
L M N O P Q R S T U  
V W X Y Z

States, Counties, Townships, Capitals and Principal Cities (all capital letters)

a b c d e f g h i j k l m n o p q r s t u v w x y z

Towns and Villages (with capital initials)

FIG. 20. Map alphabets, civil divisions.

single-stroke Reinhardt letters, either slant or vertical, except the titles, which may be made in a more ornamental style. On Geographic and United States Government maps, the lettering is in modern Roman with certain variations designed for special purposes. A competent map draftsman must be a master at this style of lettering. The styles of lettering used by the map-making departments of the Government for different features are shown in Figs. 20 to 24 inclusive.

While the lettering is about the last thing to be inked on a map,



*ABCDEFGHIJK  
LMNOPQRSTU  
VWXYZ*

Lakes, Rivers and Bays (all capital letters)

*abcdefghijklmnopqrstuvwxyz*

Creeks, Brooks, Springs, Small Lakes, Ponds, Marshes and Glaciers (with capital initials)

FIG. 21. Map alphabets, hydrography.

ABCDEFGHIJKLMNO  
PQRSTUVWXYZ

Mountains, Plateaus, Lines of Cliffs and Canyons (all capital letters)

*abcdefghijklmnopqrstuvwxyz*

Peaks, Small Valleys, Canyons, Islands and Points (with capital initials)

FIG. 22. Map alphabets, hypsography.

*ABCDEFGHIJKLMN OPQRSTUVWXYZ  
1234567890*

Railroads, Tunnels, Bridges, Ferries, Wagon-roads, Trails, Fords and Dams (capitals only)

FIG. 23. Map alphabets, public works and contour numbers.

ABCDEFGHIJKLMN OPQRSTU  
WXYZ

*abcdefghijklmnopqrstuvwxyz*

(with capital initials)

FIG. 24. Map alphabets, marginal lettering.

the placing of it must receive attention during the preliminary pencil work; otherwise, there will often be no place to put some very essential information when the work is nearing completion. As in all other types of drawing, lettering should be so placed, as far as conditions will permit, that it may be readable from the bottom and right-hand side of a drawing.

**TITLES.** — Map titles may be made in Roman or Gothic letters, and are usually in the vertical style. The purpose for which the map is to be used will determine the content of the title. The scale, graphically represented, is always to be included in all maps that are to be reduced before printing. The scale should, of course, be stated in the title of all other maps. The date is also an essential feature in all except small geographic maps. Map titles are seldom enclosed and are usually placed in the lower right-hand corner of the sheet, if possible. An open spot on the paper not filled with map details must, of course, be selected. Unless a map has on it the lines representing the meridians and latitudes, an arrow indicating the north point must also be placed at some convenient spot on the map, preferably near the title.

#### BIBLIOGRAPHY

- A TREATISE ON PROJECTIONS, by Thomas Craig. Circular No. 61, Coast and Geodetic Survey.
- TOPOGRAPHICAL DRAWING, by Edwin R. Stuart, McGraw-Hill Book Co., New York, 1917.
- ELEMENTARY SURVEYING, by Breed & Hosmer. John Wiley & Sons, Inc., New York, 1915.
- HIGHER SURVEYING, by Breed & Hosmer. John Wiley & Sons, Inc., New York, 1915.
- ELEMENTS OF MAP PROJECTION, by Charles H. Deity and Oscar S. Adams. Department of Commerce, Special Publication 68, Government Printing Office, Washington, D. C.
- PHOTOTOPOGRAPHIC METHODS, by J. A. Flemer. John Wiley & Sons, Inc., New York, 1906.

## CHAPTER XIX

### ARCHITECTURAL DRAWING

In the course of a few years' practice, every engineer, whether he be in civil, mechanical, electrical, or other special branches of engineering, will have occasion to use architectural working drawings; and it may happen that it will be necessary for him to make house or industrial building plans on his own responsibility. A general knowledge of architectural drawing will be valuable to any engineer, especially if he does contracting work.

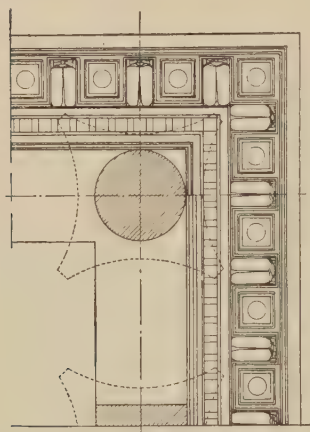
While architectural drawing covers a wider field than that included in the term working drawings, it is the purpose of this chapter to cover only that phase of it which interests the engineer from a practical standpoint. It is intended to leave to more extended treatises those questions which relate to art and design and to that phase of the architect's work having to do with the preparation of display drawings which depend for their effectiveness upon some method of rendering in shades of light and dark.

As stated elsewhere in this text, the fundamental principles underlying all projection drawing are the same, but the peculiarities of expression may vary considerably. While these variations in expression are not the main points to be emphasized, yet they should be understood in order to read an architectural drawing intelligently.

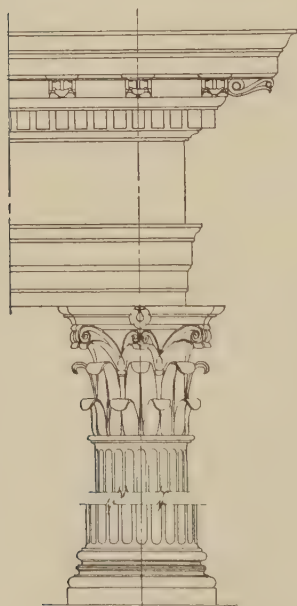
In general, architectural drawing is third-angle projection, although there are occasions when the first angle is used. Owing to the size of the building and to the fact that a plan must be made for each floor, the architect seldom thinks of his work in terms of third-angle projection. Instead, he uses one plane at a time, placing it parallel to that part of the building which he wishes to show, and then projects upon it. For example, in making the *four* elevations of a building, it is simpler to think of just one plane at a time placed parallel to the face of the building we wish to draw.

In most cases, only one plan or elevation is drawn on a sheet; hence, instead of projecting from view to view as is done in machine

drawing, the architect must resort to measurements which must be made according to the rules of projection.



PLAN OF ENTABLATURE (LOOKING UP)



ELEVATION OF BASE, CAPITAL  
AND ENTABLATURE.

FIG. 1. Reflected view.

A bottom view is used perhaps more frequently in architectural than in machine drawing. It is sometimes called a "reflected" view or a "plan looking up," and represents what would appear if one should look down in a mirror placed under the object or should look up at the under side. This is frequently done to show the detail of cornice or ceiling. See Fig. 1.

According to the purposes for which they are used, an architect's drawings may be divided into two general classes, namely, those which are used for study and consultation with clients, and those by means of which the building is actually erected. The latter are called *working drawings*, while the former are further subdivided into two classes called *preliminary sketches* and *display drawings*. The preliminary sketches are made by the architect for his own study of the problem and to use in discussion with his client, while the display drawings represent the completed solution which the architect submits in competition or for public display.

**PRELIMINARY SKETCHES.**—The draftsman begins his study of a problem by making freehand sketches embodying different ideas which occur to him. From these

he selects what appears to be the best, and works up a preliminary sketch in pencil to a small scale, say one-sixteenth of an

inch to the foot or one-eighth of an inch to the foot, for presentation to his client. These sketches may include the main floor plans, an elevation, and a perspective. They are dimensioned for general sizes only and are sometimes embellished in such a way as to make them more attractive to the client. It is essential that they shall be easily understood, since the person who is to inspect and approve them is frequently not proficient at reading drawings. To this end, only the material which will show the general arrangement is included, and the details of construction are omitted. These drawings are often made on tracing paper so that comparison of different floor plans can be readily made by placing one over the other.

**DISPLAY DRAWINGS.** — In some respects display drawings serve the same purpose as the preliminary sketches, since they make clear to others the general arrangement and appearance of the building. They are made to small scale, the exact choice depending upon the size of the building and the desired size of the finished drawing. They usually include a front elevation, the main floor plans, and a perspective. They are rendered in pencil, ink, or water colors, or in a combination of these, and include, besides the building itself, some imaginary background, such as trees, shrubbery, gardens, clouds, etc., the whole drawing being a problem in art, designed to secure the most pleasing effect and to show the building to the best advantage.

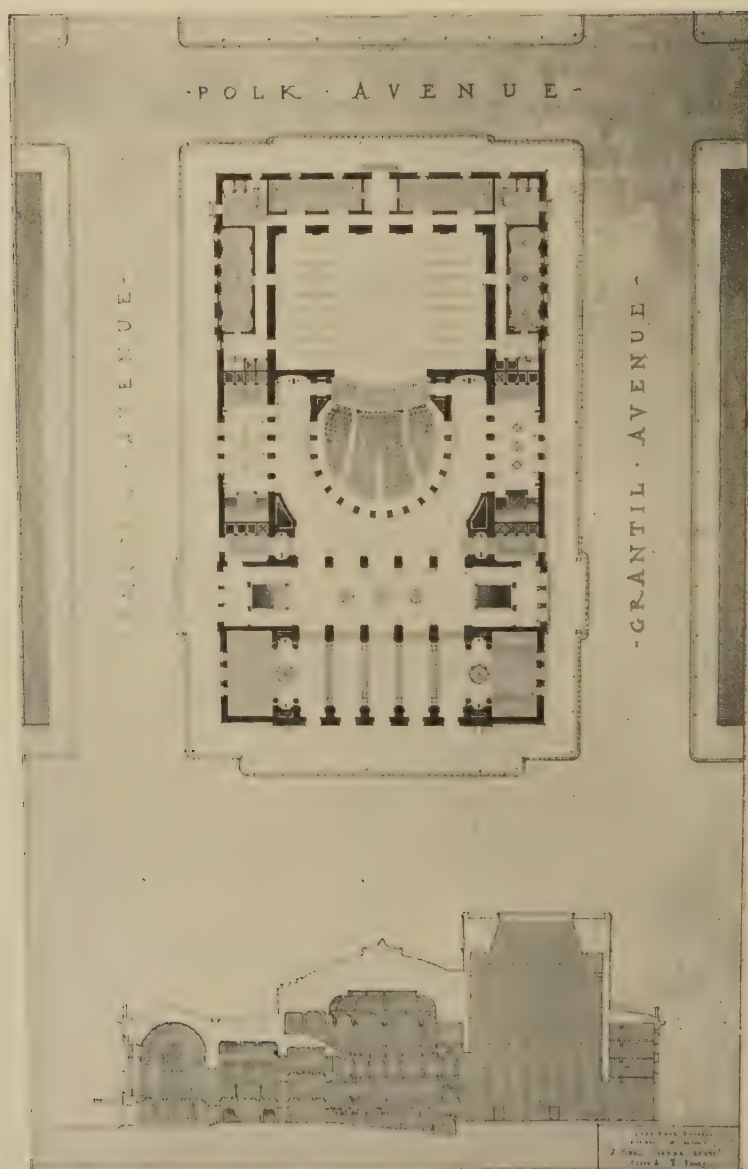
The floor plans are generally rendered in Poché and Mosaic. By Poché is meant the coloring of the walls black to make them stand out prominently, while Mosaic refers to floor designs, furniture, gardens, walks and drives, which are rendered in lighter tints and tones, as in Fig. 2.

An ordinary front elevation may be made quite realistic by putting the shades and shadows on the building and by putting in a foreground in parallel perspective.

Display drawings are not dimensioned, but the scale is represented graphically. They contain very little information that could be used by the builder. An example of a display drawing, submitted in a competition, is shown in Fig. 3.

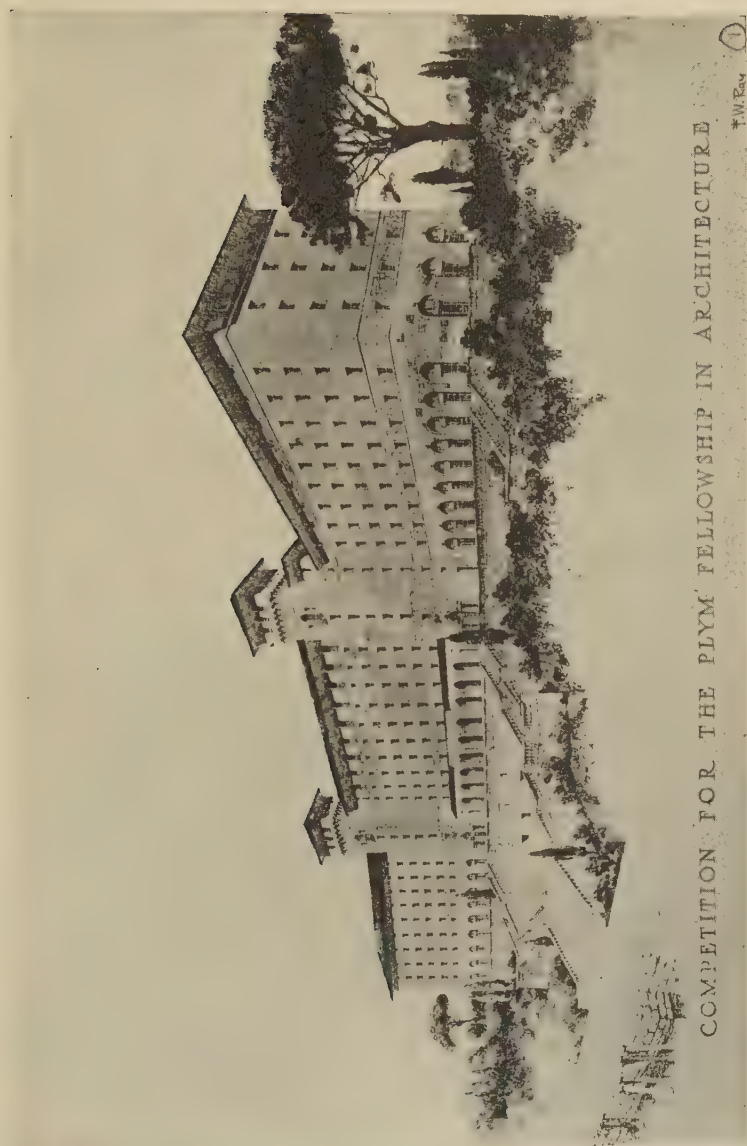
**WORKING DRAWINGS.** — The working drawings developed from the architect's sketches and display drawings are the ones in which the engineer is particularly interested. The purpose of such drawings is to provide information from which accurate estimates of cost can be made and from which the building can be constructed.





(Courtesy Department of Architecture, University of Illinois.)

FIG 2. Display drawing.



(Courtesy Department of Architecture, University of Illinois.)

FIG. 3. Display drawing.

They must, therefore, be accurately made to scale and include all necessary details and dimensions.

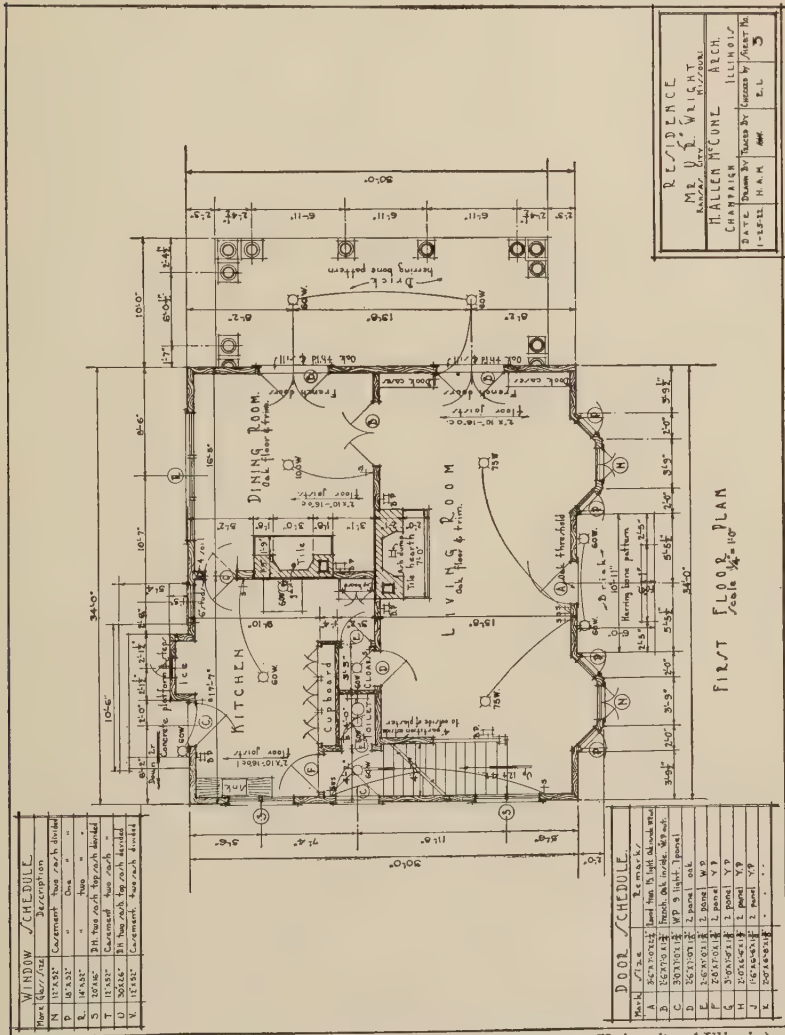
A complete set of working drawings, or set of plans, as they are sometimes called, will include the following six or more sheets: Plot Plan; Basement or Foundation Plan; Floor Plans in order, — first, second, third, and so on, not duplicating of course where the floors are exactly alike; Four Elevations, — if all views of the building are different; Sections, — as many as may be required; and Details, — as many as may be required. In addition, large buildings frequently require separate sets of plans for the structural framing, whether it be of steel or of reinforced concrete, and separate plans for the plumbing, and heating and ventilating.

**Plot Plan.** — The first sheet of a complete set of plans is the plot plan. It shows the property lines and the relation of the proposed building to them. The building is represented by a cross-hatched area whose shape is that of the outside of the structure at the grade line. In addition, there should be shown the drainage sewers and water mains, walks and driveways, and any outbuildings to be constructed. If the building site is hilly, the elevations are shown by contour lines and any grading which may be necessary is indicated. This sheet, like the others, contains in the lower right-hand corner the architect's standard title, and at some convenient place on the sheet an arrow indicating the north point.

**Floor Plans.** — The floor plan of a building, instead of being a top view as in machine drawing, is in reality a horizontal section as seen from above. The horizontal cutting plane is passed so that it will show the most detail; it need not be a single continuous plane, but may be offset to different heights above the floor at various places. The plan will, therefore, show all openings in the walls in the story through which it is passed. It will show all of the interior walls and the built-in features which are included in the building contract, such as the plumbing fixtures, special cases, cabinets, and the like. The location of heat outlets or ventilating ducts must also be shown, as well as the location of steam or hot-water radiators and their connecting lines where space must be provided for them by some one other than the heating contractor. The exact location of the water and drainage pipes for the plumbing are usually not shown on small jobs unless their location presents a problem the solution of which must be provided for in advance.

Stairways are indicated by showing approximately one half of the full flight to the floor above and the floor below, either more or

less as the conditions may require, and by marking upon the drawing the full number of risers. An illustration is shown in the floor



(Courtesy Department of Architecture, University of Illinois.)

FIG. 4. First floor plan.

plans in Figs. 4 and 5. Two consecutive floor plans must therefore show completely the stairway connecting them.

Stairways are frequently worked out to a large scale in order to make sure that they will properly fit in the space allowed. A com-





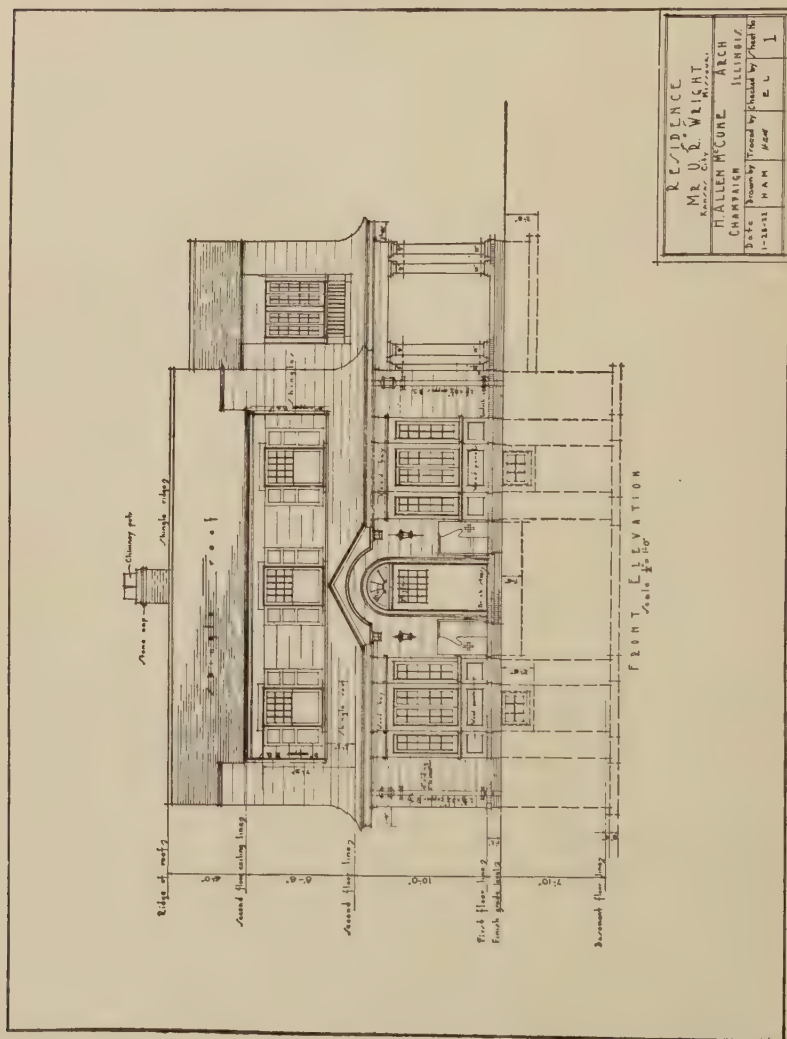
rules of projection. For example, beams and ornamental features which appear in the ceiling above the floor shown, are indicated on the floor plan. The lintels over wall openings are also indicated, although they are above the cutting plane. In small buildings not requiring separate framing plans, the supporting members for the floor above are shown on the plan of the floor below. Thus, the beams supporting the fourth floor would be indicated on the third floor plan. This, of course, does not apply where a special set of framing plans is prepared. Ceiling lights and outlets are indicated in the same way, by locating them on the plan of the floor below. The actual location of the wiring is not given, unless openings must be allowed for it by others than those who do the wiring. In reinforced concrete work, for example, holes must be provided where wiring conduits pass through floors or beams, as the cutting of holes after the concrete is poured and set might damage its structural value.

It has become an established practice to draw the floor plans so that the front of the building is toward the bottom or right edge of the sheet, depending upon the shape and size of the building. Elevations should read from the bottom of the sheet, or the right-hand edge in some instances.

In making the floor plans of a building that has several stories, time may be saved by tracing from the first floor plan the outside walls and interior columns which run through from floor to floor. This also avoids the possibility of error in the location of columns or piers, elevator shafts, and the like, which must line up from story to story.

**Elevations.** — The elevation of a building is simply a projection of any side upon a vertical plane parallel to it, and shows the story heights, all openings in the outside walls, and the nature of the outside finish, such as stone, brick, ornamental iron, etc. Unless the sides of a building are identical, each elevation should be drawn. Where ornamental designs are worked out in brick, the general arrangement and location is shown on the elevation, and the exact construction is shown in a large-scale detail drawing. The portion of the building below the grade line is shown in dotted lines, as are also roof lines which may be concealed behind parapet walls. On elevations of small buildings, stairways are sometimes drawn in dotted lines in order to save drawing a section. With these exceptions, the invisible line is not used on the elevation unless absolutely necessary. Dimensions on an elevation are practically lim-

ited to those in a vertical direction. Other dimensions belong on the floor plans and should not be placed on the elevation unless it

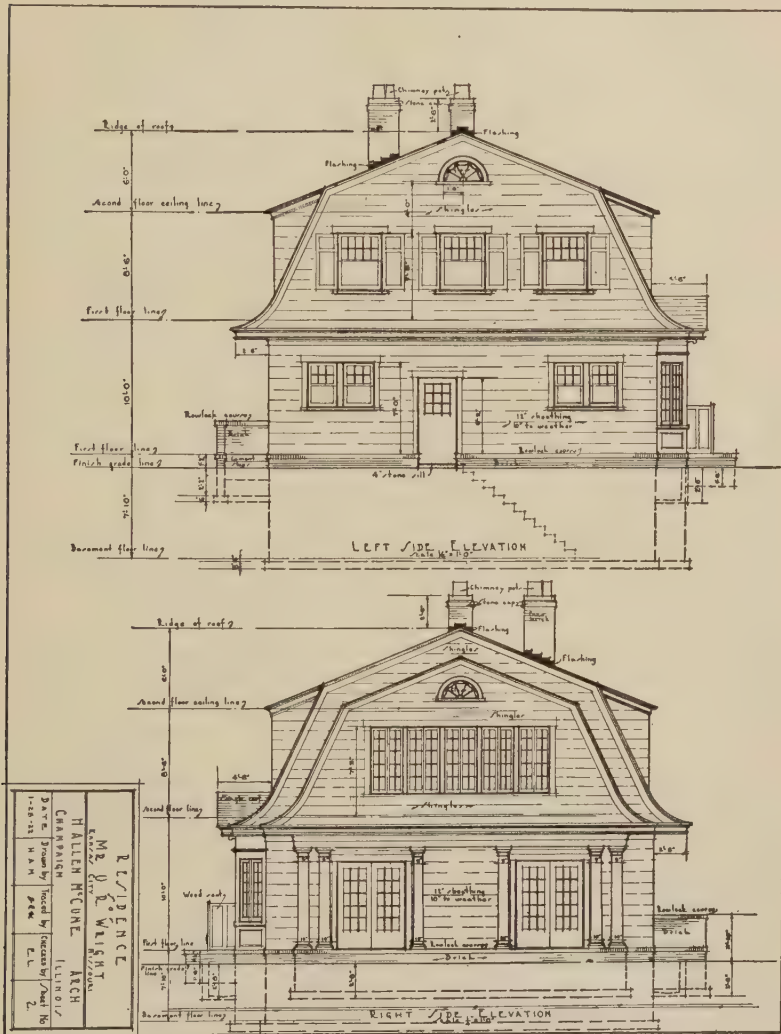


(Courtesy Department of Architecture, University of Illinois.)  
FIG. 6. Front elevation.

is impossible to show them on the plans. Figures 6 and 7 show the elevations of a frame building.

The elevations are given life and snap by shade lining and touches of ruled line rendering to suggest the texture of the surface.

This ruled line rendering must be soft and subdued, and not an attempt at a rigid representation, as in machine drawing. By



(Courtesy Department of Architecture, University of Illinois.)

FIG. 7. End elevations.

the term shade lining, used above, is meant making heavier and more prominent those lines and edges of the building which cast a shadow, or those lines which separate surfaces in shadow from those which are in direct light.

When the façade or front of a building is symmetrical about its center line, time and labor may be saved by making only one half of the front elevation and devoting the other half to a section.

**Sections.** — The floor plans and elevations are insufficient to show all of the interior construction and it is, therefore, necessary to show one or more sections taken at carefully selected places. If the section is cut across the narrow way of the building, it is called a transverse section; if cut lengthwise, it is called a longitudinal section. In addition to the longitudinal and transverse

| <i>MATERIAL</i>    | <i>PLAN</i> | <i>SECTION</i> | <i>ELEVATION</i> |
|--------------------|-------------|----------------|------------------|
| <i>BRICK</i>       |             |                |                  |
| <i>TILE</i>        |             |                |                  |
| <i>TERRA COTTA</i> |             |                |                  |
| <i>STONE</i>       |             |                |                  |
| <i>CONCRETE</i>    |             |                |                  |
| <i>PLASTER</i>     |             |                |                  |
| <i>WOOD</i>        |             |                |                  |
| <i>METAL</i>       |             |                |                  |

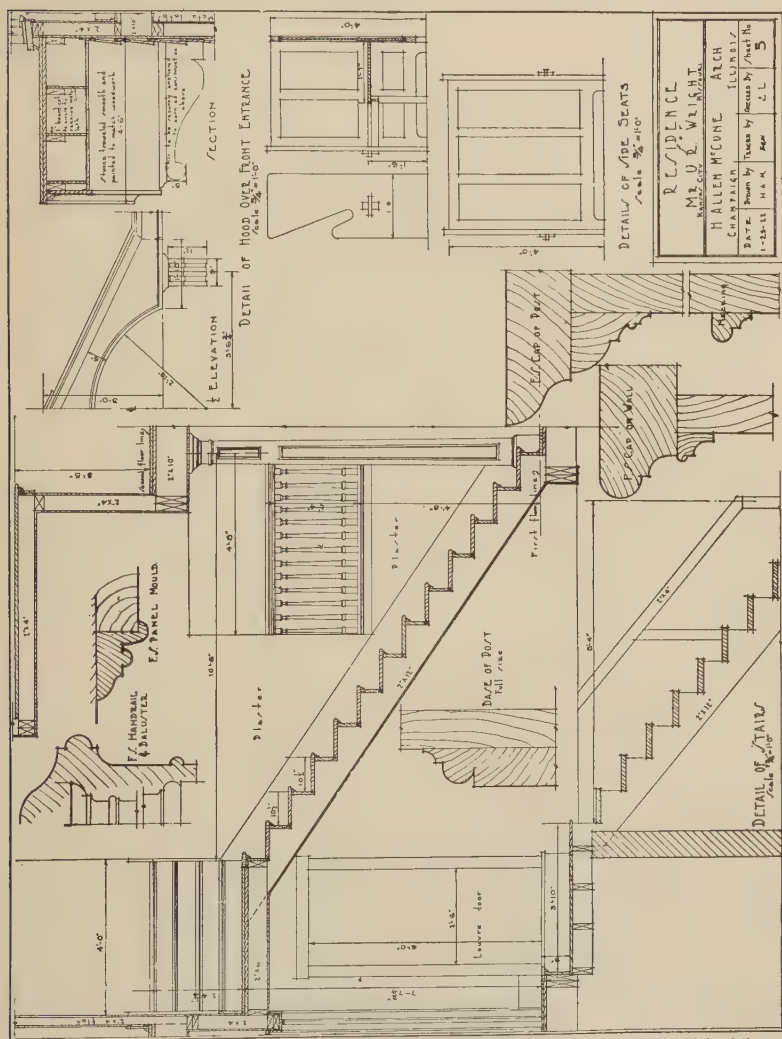
FIG. 8. Standard materials symbols

sections, other sections may be taken of any part of a building, not necessarily clear across it but usually cutting entirely across some part that is a unit in itself. Cross-sections of the minor parts of a building, as for example a foundation or parapet wall, are called detail sections.

In drawing the cutting plane for a section, it need not be made as one continuous plane but may be offset one or more times to take in the important features which it is desired to show. The cutting planes are always placed perpendicular to the principal axes of the building, and the offsets parallel thereto. The location of the cutting plane is shown on each floor plan by a heavy dash and dot line, with arrows at its ends outside the building line indicating the direction in which the view is taken. All parts which are cut by the plane are shown cross-hatched in some characteristic way, to represent the material, as shown in Fig. 8. All other parts lying

behind the plane are shown in the usual way. Invisible lines are avoided.

**Details.** — Because of the small scale, it is impossible to show the



(Courtesy Department of Architecture, University of Illinois.)

FIG. 9. Architectural details.

exact construction of all parts of a building on any of the drawings just discussed. It is, therefore, necessary to draw typical details of all intricate parts of the building for which the construction is



not self-evident or in accordance with standard practice. These details are made to a larger scale than the rest of the drawing and may vary from one-half inch to the foot up to full size. See Fig. 9. It is quite evident that an architect cannot include everything

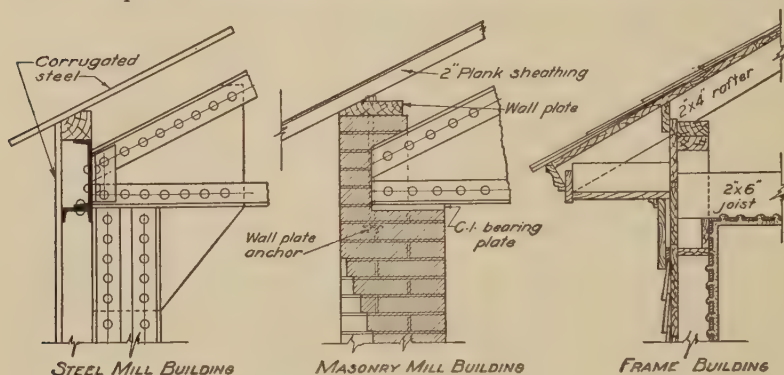


FIG. 10. Eave details.

that may need explanation, but his plans should embrace enough details to permit the making of an accurate estimate. It would be manifestly unfair for him to insist upon some type of construction not fully shown in the plans, when the contractor had perhaps fig-

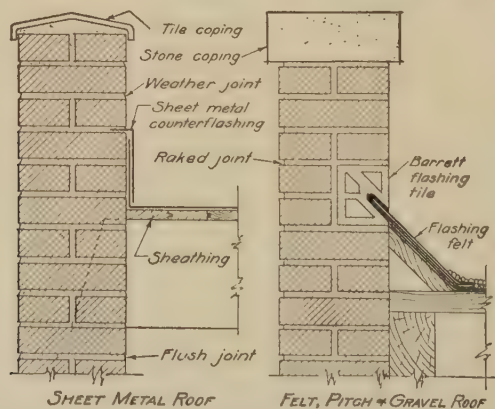


FIG. 11. Parapet wall details.

ured on some cheaper scheme. As the building operations proceed, however, the architect is required, from time to time, to furnish additional detail drawings, which must always be given a title showing clearly to what part of the building they apply.

The architect does not devise all of the details which are shown in his plans, but depends upon the manufacturers of the different products which go to make up a building to supply him with information concerning their products. Such information has been col-

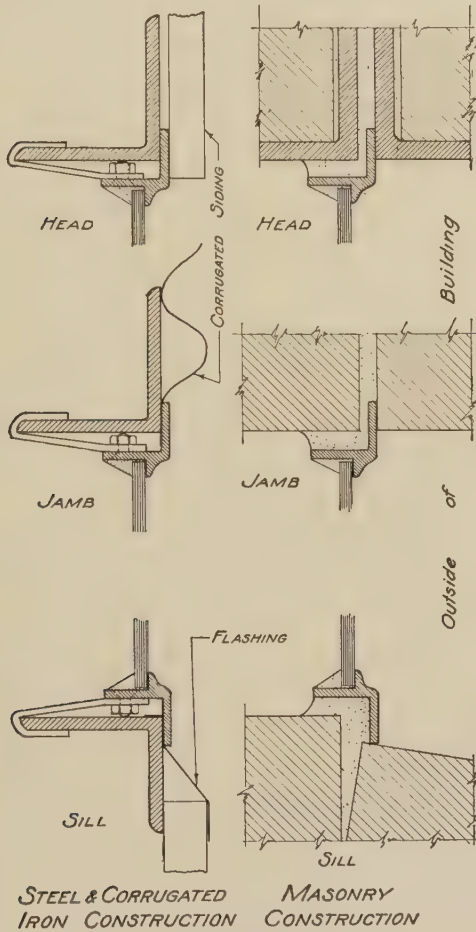


FIG. 12. Steel sash details.

lected in a book, called "Sweet's Architectural Index." A similar index for engineers is also on the market. The progressive architect or engineer also keeps a file of the catalogues of all the manufacturers of materials in which he is interested.

**Dimensioning.** — The common rules which apply to machine drawing hold in general for architectural drawing. It is, however, a little more difficult to tell what to dimension, as it is only by experience that one can learn which dimensions, of the many that might be given on a building plan, are of any value to the workman. Where dimensions are given, they must be clear, definite, and unmistakable. Moreover, they must check with each other from place to place and from plan to elevation. In other words, care must be exercised to see that the same thing is not represented as of one size on the plan and as of another size on the elevation. The inevitable variation in commercial sizes of material must be taken into consideration. This does not lessen the requirement for accuracy but demands an expert knowledge of building operations on the part of the architect. Several points to be observed in dimensioning are as follows:

1. Keep all outside dimension lines well away from the building lines. The nearest line should be about an inch away from the building line.

2. Dimension to center lines of interior walls or to the outside of walls and then give the thickness also. Whenever possible, make a series of inside dimensions in one straight line clear across the building line. See Figs. 4, 5 and 7.

3. Dimension to the center lines of columns in both directions.

4. Dimension to the center line of openings in outside walls, unless the exact size of the opening is to have a specific value not affected by any variation in commercial sizes of materials.

**Notes.** — More notes are used in architectural drawing than in any other branch of engineering drawing. When there is any doubt as to the meaning of a symbol, this should be made clear by a note. When a part is detailed, a brief note, such as "See detail on sheet No. 11," should be placed on the floor or elevation drawings near the part detailed. Then under the detail itself there should be a title stating what it is, and a note referring back to the place where the parts may be found in the drawings. In addition to these notes, the sizes of doors, windows, beams, girders, lintels, columns, etc., must be given. These might be classified as dimensions, but since they do not appear in dimension lines it is better to call them notes.

**Specifications.** — Even with all the drawings and notes referred to heretofore in this chapter, it is impossible to give all of the information which is necessary for the proper construction of a building. In order to make everything clear, the architect prepares what is

termed a "set of specifications," to accompany each set of plans. These specifications begin with the general terms of the contract, and then proceed in an orderly and logical manner to consider the work of the various trades that are involved in the construction of the building. The specifications cover those points of construction which cannot be shown in a drawing, namely, quality of materials, kind of finish, color of decorations, particular kinds of construction, such as thickness of mortar joints, kind of bond, etc., and in addition they re-emphasize such points as might be overlooked if the drawings alone were used.

**Symbols.** — Since working drawings are made to a scale of one-fourth or one-eighth inch to the foot, building plans must take on a

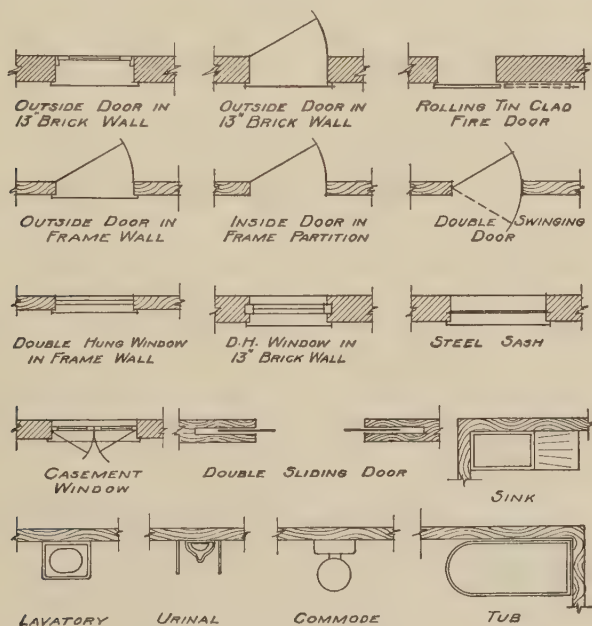


Fig. 13. Architectural symbols.

rather conventional nature. It is not possible to show every edge and surface by a line, as is done in machine drawing; hence, most of the building parts must be represented by symbols which are made carefully to scale and show as nearly as possible the appearance or construction of the thing represented. For example, of the many lines which actually must be drawn in a large-scale detail of a window, only those few which most clearly show its nature and

construction are possible in the small-scale symbol. This is made quite clear by a comparison of the window detail in Fig. 14 and the symbol for a double hung window in Fig. 13. The scale of the symbols in Fig. 13 is one-eighth inch equals one foot. A casual examination of these illustrations makes clear at once that more

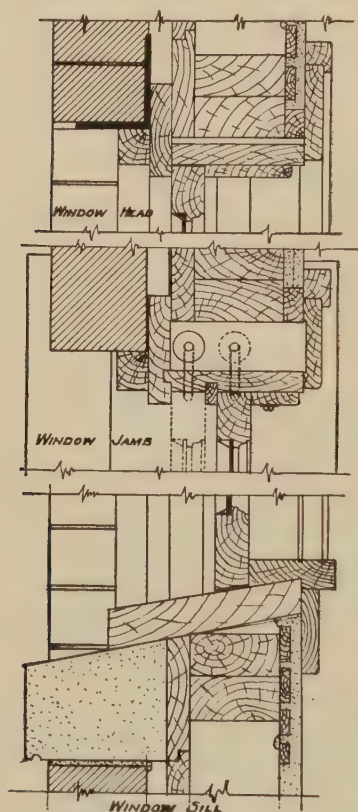


FIG. 14. Window detail.

than ordinary skill and care must be exercised in making symbols even to a scale twice this size. It is clear also that the smaller the scale the simpler the symbol must become. A common fault of beginners is to make the symbols too large and bungle-some in proportion to the rest of the drawing.

The symbols shown in Fig. 13 are practically standard for the objects and scale shown, although some variations will be found. These variations, however, are very readily intelligible to anyone familiar with building construction, and offer no obstacle to the reading of the drawings.

Many features of a building are not standard at all; hence, the architect requires a knowledge of their construction in order to represent them by a small-scale symbol. To represent such parts, he has recourse to large-scale details and, from them or his own intimate knowl-

edge, devises symbols to represent the parts.

Different materials are represented by various kinds of cross-hatching. Since such cross-hatching is not standardized, it is a common practice for architects to place on each set of drawings a key showing the particular cross-hatching they are using for each material. Such a key is shown in Fig. 8. To one familiar with building plans and operations, the cross-hatchings shown and commonly used in practice are readily understood without a key, except in the case of special materials not commonly used.



**Titles.** — Architectural titles are usually placed in the lower right-hand corner of the sheet, although occasionally one will find a drawing where the title has been put in some other place. The style of lettering usually employed is a single-stroke, free imitation of the Roman. The title generally displays the name of the architect, or firm of architects, rather prominently. The name of the building, if public, or the name of the owner, is also given prominence in the title. The contract number, the sheet number, the scale, and the names of the draftsman, tracer, and checker, and the approval signature of the architect are also included. The same general title is placed on each sheet, with a change, of course, in the sheet number and other details where necessary. Other information concerning the drawing on the sheet is placed below the views, as for example, FIRST FLOOR PLAN, EAST ELEVATION, etc., and not in the title space itself.

**Technique.** — The technique of architectural drawing is similar in many respects to that of machine drawing. Visible outlines, such as walls, beams, columns, etc., are made heavier than center lines, dimension lines, and cross-hatching. All lines should be lighter than those generally used in a first-class machine drawing, in order to show adequately the many small details. Contrast between the weights of lines in these two groups, and perfect uniformity throughout the group itself, will give the drawings a vigorous and workmanlike appearance.

There is, however, a little greater freedom in the architect's technique, by which he gives expression and life to the drawing, than is permissible in other fields of drawing, although greater freedom does not mean less accuracy. The over-running of corners is a common practice not found in other engineering drawings, and though it may speed up the work somewhat, care should be exercised not to over-run where confusion might result.

On elevations, shade lining and ruled line rendering are used for embellishment of the drawing. There are also many details which the architect must put in freehand. These give character to the work, and produce an effect which is entirely different from the hard and rigid appearance of machine drawings. These elements, together with the greater freedom in the style of lettering, constitute the chief differences between the technique of architectural and machine drawing.

**Lettering.** — The architect must employ his knowledge of lettering in two ways, first, in the lettering of his drawings, titles, and the like, and second, in the design of inscriptions and memorial tablets,

which constitute a part of the ornamentation of a building. For inscriptions, the old Roman or modern Roman is most frequently used and the lettering is laid out with instruments. Examples of the Roman alphabet are shown in Chapter II of Part I. Such lettering constitutes a problem in design with which the engineer is not concerned.

On working drawings, a single-stroke modification of the Roman alphabet is used for titles and sub-titles, while the single-stroke Gothic is most frequently employed for notes. The freak letters commonly seen in the work of some architectural draftsmen should never be used in notes on working drawings and are to be avoided even in legends and titles.

#### BIBLIOGRAPHY

- ARCHITECTURAL DRAFTING, by Greenberg and Howe. John Wiley & Sons, Inc., New York, 1913.
- ARCHITECTURAL DRAWING, by Wooster Bond Field. McGraw-Hill Book Company, New York, 1922.
- THE ARCHITECTS' AND BUILDERS' HAND BOOK, by Frank E. Kidder. John Wiley & Sons, Inc., New York, 1921

## CHAPTER XX

### STRUCTURAL DRAWING

Structural drawing includes all layout problems connected with the design and construction of buildings, bridges, viaducts, and similar structures, in which structural steel, timber, concrete and other building materials are used. There have been developed certain standard practices and conventions in this field of drafting quite unlike those prevailing in Machine Drawing, although merging somewhat with those found in Architectural Drawing.

For the sake of simplicity of treatment, and because wood, concrete, and similar structures present no peculiarly difficult applications of general drafting principles, this chapter will deal with details affecting the proper representation of structures in which structural steel is used as the chief load-bearing material. As stated in the Introduction to Part II, no attempt is made to deal with the engineering design of any steel structure. However, where the simpler elements of empirical design are necessary to the clear understanding of the drafting problem involved, they have been introduced, and proper reference has been made to the source from which the student can learn the reasons why certain things are done as they are.

In order that later portions of this chapter may be clear as to the meaning of certain expressions, already quite familiar to the structural engineer, a glossary of the more common terms used in structural work is given below. Where the term **member** is used in these definitions, a unit part of some larger structure is meant. This unit part itself may be constructed of numerous pieces of steel, but it functions as a single piece and is designated as such. Thus, any part of a structural framework, such as a floor beam or post in a steel bridge, may be spoken of as a member.

#### DEFINITION OF COMMON TERMS USED IN STRUCTURAL DRAFTING ROOMS AND FABRICATING PLANTS

*Batten Plate.* A small plate used near the ends of built up members to hold two parts of any member in their proper position. See Fig. 1.

*Bay.* The space between two consecutive sets or tiers of columns and beams, or columns and trusses. See Fig. 2.

*Bent.* A vertical framework, usually columns and beams supporting other members. In Fig. 2 the truss and two columns supporting it constitute a bent. Figure 3 shows a bent as used in railroad trestles or on viaducts.

*Cantilever.* A beam, girder, or truss in which one end or both ends project beyond the supports.

*Chord.* The top or bottom members of a truss. See Fig. 2.

*Clearance.* The space left between members to allow for the slight inaccuracies of cutting, and also to facilitate erection. See Figs. 4 and 15.

*Clip Angle.* A small angle used to fasten light connections. See Fig. 15.

*Column.* A vertical compression member, usually supporting beams and girders. See Fig. 2.

*Cope.* To cut out a part of the top or bottom flange of a beam or channel so that it may fit another. See Fig. 4.

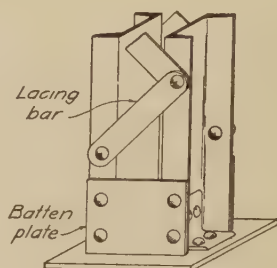


FIG. 1. Column base.

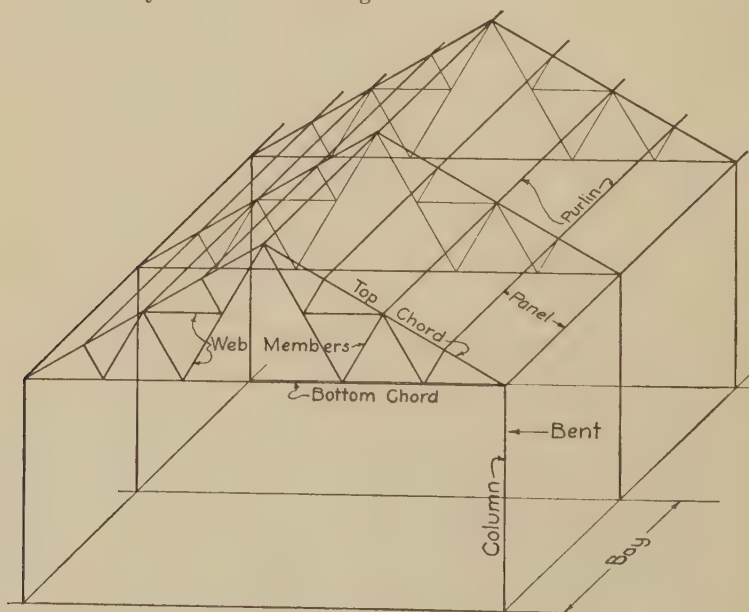


FIG. 2. Line diagram, mill building.

*Cover Plate.* A plate riveted to the flanges of a compression member to give it greater area. The plates on the top flange of a plate girder are perhaps the most common examples. See Fig. 6.

*Filler Plate.* A plate used to fill in empty spaces through which rivets must pass, as for example, under stiffeners on a plate girder. See Fig. 6.

*Flange.* The top and bottom projection or outstanding parts of a beam, channel or girder. See Figs. 4 and 6.

*Gage Line.* The line along which rivet holes are punched in structural members. See Figs. 5, 6, and 14.

*Girder.* A member designed to carry bending stress, usually supporting other members. Figure 6 shows one end and a section of a girder.

*Gusset Plate.* A plate connecting the several members of a truss or other structural framework. See Figs. 5 and 14.

*Lattice Bar or Lacing Bar.* One of a series of short diagonal bars used to connect the several parts of a member. See Fig. 1.

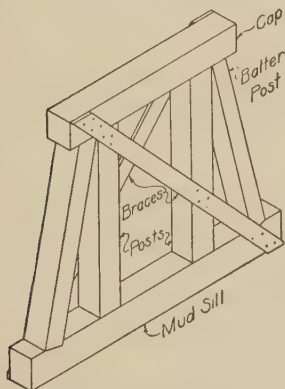


FIG. 3. Railroad trestle bent.

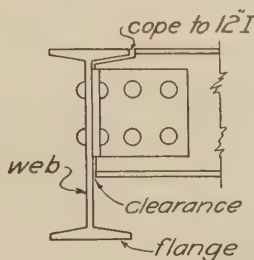


FIG. 4. I-Beam connections.

*Lintel.* A structural member designed to carry the wall over a window, door, or other opening. See Fig. 7.

*Panel.* The space between two purlins in a roof or between two vertical members in a bridge truss. See Fig. 2.

*Pitch.* The ratio of the height of roof to its width.

*Purlin.* The horizontal members spanning from truss to truss, upon which the roof is carried. See Fig. 2.

*Stiffener.* An angle riveted to a plate to prevent it from buckling. See Fig. 6.

*Truss.* A steel framework whose members take only tension or compression stresses. See Figs. 2, 5, and 14.

*Web.* The portion of an I-beam, channel, or girder, between the upper and lower flanges. See Figs. 4 and 6.

*Web Member.* The members of a truss between the top and bottom chords. See Fig. 2.

**SCOPE OF STRUCTURAL DRAWING.** — Professor Ketchum, in his Handbook for Structural Engineers,<sup>1</sup> says: —

“the plans (drawings) for a structure must contain all the information necessary for the design of the structure, for ordering of the material, for fabricating the structure in the shops, for erecting the structure, and for making a complete estimate of the material used in the structure. Every complete set of

<sup>1</sup> Handbook for Structural Engineers, by M. S. Ketchum, published by McGraw-Hill Book Co.



plans for a structure must contain the following information insofar as the different items apply to the particular structure.

"General Plan. — This will include a profile of the ground; location of the structure; elevations of the ruling points in the structure; clearances; grades (for a bridge); direction of flow, high water, and low water; and all other data necessary for designing the substructure and the superstructure.

"Stress Diagram. — This will give the main dimensions of the structure, the loading, stresses in all members for the dead loads, live loads, wind loads, etc., itemized separately; the total maximum and minimum stresses; size of members; typical sections of all built members showing arrangement of material; and all information necessary for the detailing of the various parts of the structure.

"Shop Drawing. — Shop detail drawings should be made for all structural steel and iron work and detail drawings of all timber, masonry and concrete work.

"Foundation or Masonry Plan. — The foundation or masonry plan should contain detail drawings of all foundations, walls, piers, etc., that support the structure. The plans should show the load on the foundation; the depth of the footings; the spacing of piles where used; the proportions for the concrete; the quality of masonry and mortar; the allowable bearing on the soil; and all data necessary for accurately locating and constructing the foundations.

"Erection Diagram. — The erection diagram should show the relative location of every part of the structure; shipping marks for the various members; all main dimensions; number of pieces in a member; packing of pins; size and grip of pins; and any special feature or information that may assist the erector in the field. The approximate weight of heavy pieces will materially assist the erector in designing his falsework and derricks.

"Falsework Plans. — For ordinary structures it is not common to prepare falsework plans in the office, this important detail being left to the erector in the field. For difficult or important work, erection plans should be worked out in the office and should show in detail all members and connections of the falsework, and also give instructions for the successive steps in carrying out the work. Falsework plans are especially important for concrete and masonry arches and other concrete structures and for forms for all walls, piers, etc. Detail plans of travelers, derricks, etc., should also be furnished the erector.

"Bills of Material. — Complete bills of material, showing the different parts of the structure with their marks, and the shipping weight, should be prepared. This is necessary in checking up the material to see that it has all been shipped or received, and to check the shipping weight.

"Rivet list. — The rivet list should show the dimensions and number of all field rivets, field bolts, spikes, etc., used in the erection of the structure.

"List of Drawings. — A list should be made showing the contents of all drawings belonging to the structure."

Of this list of drawings which are necessary for the building of a structure, this chapter concerns itself only with Shop Drawings.

**SHOP DRAWINGS.** — Two general schemes of making shop drawings are in common use. In the first and most common method, all of the work is completely detailed, down to the location of every hole and the determination of the size of every rivet, so

that the template maker and the man in the shop can proceed directly to lay out, cut, punch and assemble the material without calculation or further drawing on their part. The advantages of this method lie in the fact that an exact estimate can be made from such a drawing and that, in the event of changes or additions at a later date, complete and accurate records are available. A roof truss detailed in this manner is shown in Fig. 14.

In the second method, much of the detail is left to the template maker. The working lines of the pieces are given, together with the dimensions between working points or intersections of the gage

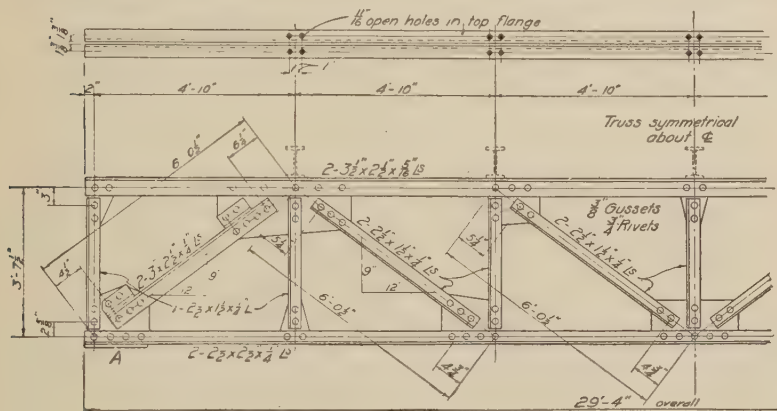


FIG. 5. Sketch detail of truss.

lines of the various members, the number of rivets in each member, the maximum and minimum rivet spacing allowed, the clearances required, and the thickness of plates and size of other structural parts. The actual layout of the rivets, the shape and size of the plates, etc., are left for the template maker to work out, full size, in the shop. Figure 5 shows a detail made in this manner.

**Number and Location of Views.** — As in machine drawing, third-quadrant projections are used entirely, and two or three views of an object are drawn, as the case may require. The top view appears above the front view, and the end view to the right or left of the front view. If the top member is inclined, the top view will be an auxiliary projection, rather than a projection on the horizontal plane, as for example, the top chord of the truss in Fig. 14. Frequently, however, in the case of very simple pieces, only one view is necessary, since the shapes of the pieces in the other direction are known to have a certain standard form. In blocking out the views.

care should be taken to allow ample space for dimensions, more space being required between views for this purpose than is ordinarily the case in machine drawing.

**Bottom View.** — In addition to the usual three views, it is frequently necessary to show a bottom view of structural members. In structural drafting, such a bottom view is made as a horizontal

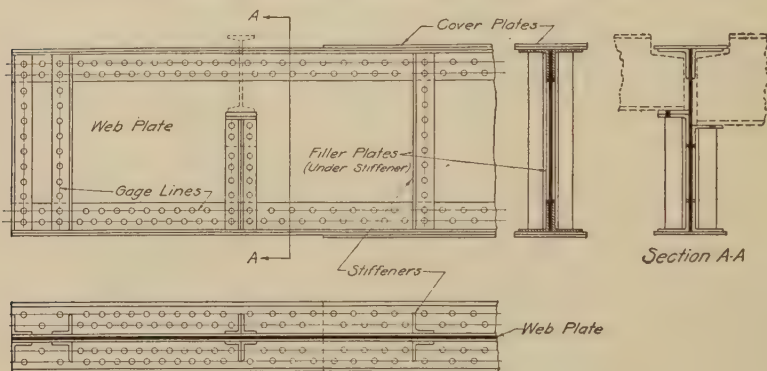


FIG. 6. Plate girder.

section looking down, instead of the regular bottom view, such as would be made in machine drawing. The horizontal cutting plane is passed to show as little other detail beside the bottom members as possible. An illustration of this practice is shown in Figs. 6 and

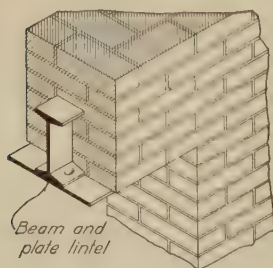


FIG. 7. Steel lintel.

14. The purpose of this practice is to show the front and back details of a girder, for instance, on the same side of the horizontal center lines in both the top and bottom views. This arrangement shows their actual relation to each other better than would be the case if a theoretical bottom view were taken.

**Details.** — In machine drawing it is customary, in making a detail working drawing, to separate the parts of a machine and detail them individually, whereas in structural drafting the opposite may be said to be the common practice. In other words, all the parts of a member are detailed as far as possible in the place they occupy in the structure. For example, the members of an ordinary roof truss are detailed in their proper places in the truss,

as are the parts of a plate girder, or the large posts and chords of a bridge. That is to say, beams and girders are detailed horizontally on the sheet, and columns are detailed vertically, unless they are too long to be placed in that position, in which case the bottom end is placed at the left of the sheet and the column detailed horizontally. Inclined or sloping members are sometimes detailed in the position which they occupy, as indicated in Fig. 8. When they cannot be conveniently detailed in this manner, they are placed horizontally in the position in which they would fall.

Where the member detailed is a part of a larger structure, its position in the completed structure is shown by a heavy line in a

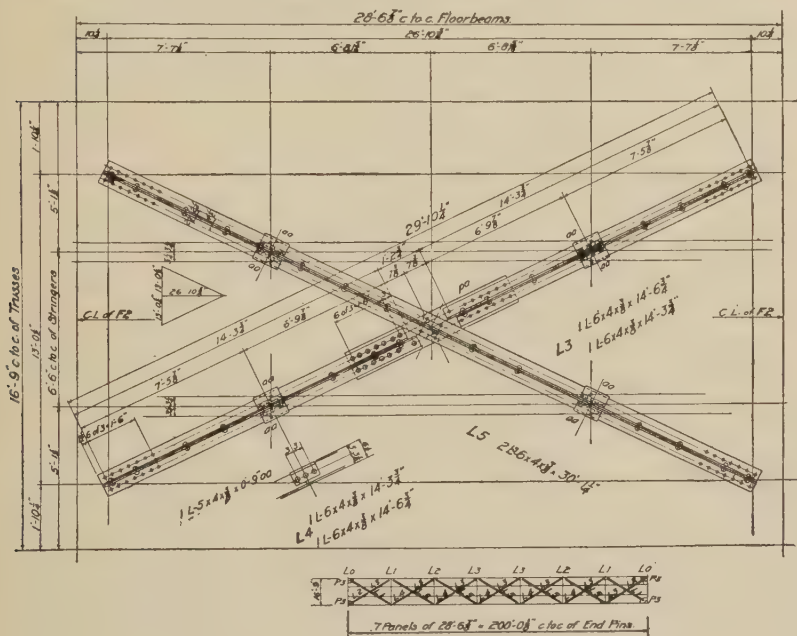


FIG. 8. Detail of wind bracing.

small sketch on the sheet, as shown in Fig. 8. This holds true for all except plain building work. Where connections occur in building work, upon the detailing of which other framing depends, the member connecting with the one detailed is shown in red ink or light, dotted, black lines, for the benefit of other draftsmen or the erector, who may wish information concerning the connecting piece. Figure 9 shows such a connection, the connecting member being shown in dotted lines.



**Symmetrical Members.** — When large members are symmetrical about a center line perpendicular to their longest dimension, only one half is detailed. It is the standard practice to show the left half when looking toward the side having the principal connections. In the case of a railroad plate girder, this requires that the inside left end of the far girder be shown as the front view. Figure 14 illustrates this in the case of a roof truss. As may be noted in this case, the detail should be carried far enough past the center line to

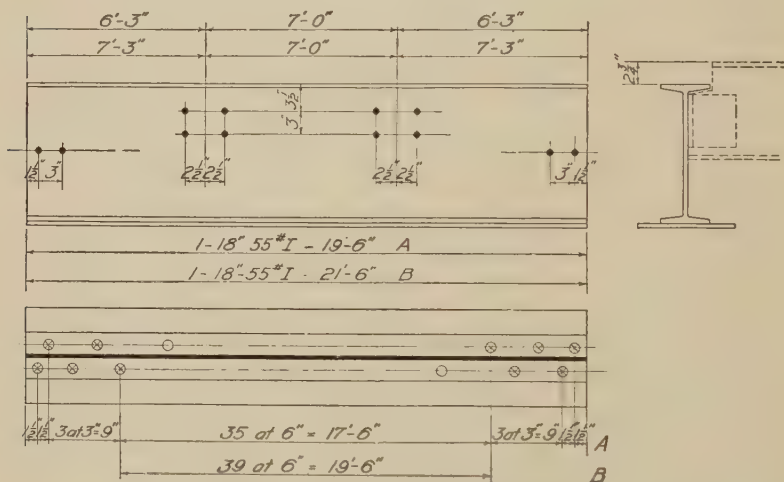


FIG. 9. Detail of steel lintel.

show any variation that may occur at the center. In no case should the detail be stopped exactly on the center line, even though there may be no variation beyond. The member should be broken off beyond the center by a ragged or wavy line, or the lines of the drawing may be simply stopped at the same place. The wavy line should be drawn only where there are members actually broken off, and not through the space between members.

**Sectional Views.** — Sections are frequently necessary in structural drawing and may be made in the positions occupied by end views or interpolated sections in machine drawing. When several sections of the same piece are necessary, these may be put in convenient places on the sheet and noted as sections taken at some particular plane, as, for example, *Section A A*. The place where this section is taken is then indicated on the drawing by a line *A A*, with arrows on the end of it to indicate the direction of sight, as in Fig. 6.



Standard practice as regards cross-hatching is also shown in Fig. 6. The main part of the member cut is usually made solid black, although cross-section lines may be used. Filler plates, stiffeners, etc., need not be cross-sectioned.

**STANDARD DETAILS.** — Through long years of practice and experience, certain details of steel construction have become standardized. The draftsman and detailer should adhere to these standard details unless it is impossible to do so, or unless some particular advantage is to be gained by departing therefrom. Some of the more important and common standards are discussed in the following paragraphs.

**Standard Structural Shapes.** — The shape, dimensions, and consequently the weight of structural sections are thoroughly stand-

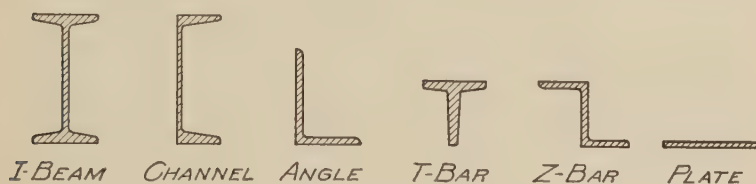


FIG. 10. Cross-section of structural shapes.

ardized and the general dimensions of the more common pieces should be familiar to the draftsman. Figure 10 shows cross-sections of the more common shapes, the sizes of which vary through a wide range although the general proportions remain about the same. Thus, I-beams may be obtained in sizes from 3 to 36 inches in height, and for each height there are a number of standard weights. The structural steel handbooks list all of these completely, and the student is referred to them for further information. A list of the standard light sections is given in the Appendix.

**Gage Lines.** — The lines along which rivets should be placed in the flanges of I-beams, channels, angles and other structural shapes has become standardized through long usage. These lines are called gage lines. In the case of angles, the gage line is measured from the back of the angle. The gage line in the flange of a channel is also measured from the back of the channel, but in the flanges of an I-beam the gage lines are measured from the center. Edge distances are not given because they vary along the same beam, and they also vary in shapes of different weight, whereas the distance measured from the back or center line always keeps the gage lines

in the same relative position. A table of standard gages for I-beams, channels, and angles is given in the Appendix.

**Rivet Size and Spacing.** — Maximum and minimum distances for rivet spacing along the gage lines have also been established. A table of these spacings is given in the Appendix.

Since there is a certain clearance required in driving rivets, there is a limit to the size of rivets which may be driven in the standard shapes. A table of maximum sizes for I-beams, channels, and angles is given in the Appendix. Figure 11 shows the shape and size of the dies used in driving rivets. The minimum size rivet is governed by the following rule: the diameter of the rivet should never be less than the thickness of metal to be punched. That is to say, a hole for a one-half inch rivet should not be punched through three-quarter inch metal.

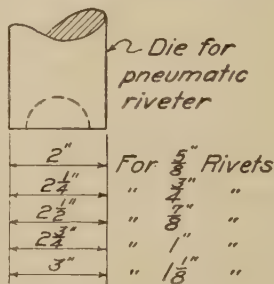


FIG. 11. Size of dies for rivet heads.

The end and edge distance of rivets from sheared or rolled edges of members, together with the maximum and minimum pitches allowed, is given in the Appendix.

Beside these fundamental standards, others have become well established as, for example, the connection for beams and channels framing into columns or other beams as shown in Fig. 12. Built-up columns are also standardized. These standards and all others may be found in the handbooks of the various steel companies.

Every engineer should have a copy of one of these standard handbooks, which may be purchased direct from the steel companies. Another book which is indispensable to the structural engineer is a Smoley's or Inskip's Tables of Squares.

**DETAILING A TRUSS.** — To illustrate the procedure in structural drafting, and to explain the previous paragraphs more fully, we shall consider the various steps required in making a detail of a simple roof truss.

Assume that complete information is given the draftsman in a design sketch, as shown in Fig. 13. Since the truss is symmetrical, it will only be necessary to show the left half, up to and including the center points.

The first step, after deciding upon the number and arrangement of views and selecting a scale to fit the requirements, is to lay out





angle. These three lines, which together represent the angle, can be marked off with one setting of the scale and then drawn in very quickly.

In the same way the other angles may be drawn around their corresponding working lines. The ends of the angles should in most cases be shown cut off at right angles to their length as a matter of economy. When all of the angles have been drawn, the proper number of rivets may be put in at each point to the same scale as that used in laying out the angles. The rivet spacings may be scaled from the end of the angles using the standard end distance and standard spacing the design calls for. After all the rivets have been properly located, the gusset plates may be drawn in to scale, care being taken to provide the proper edge distance from

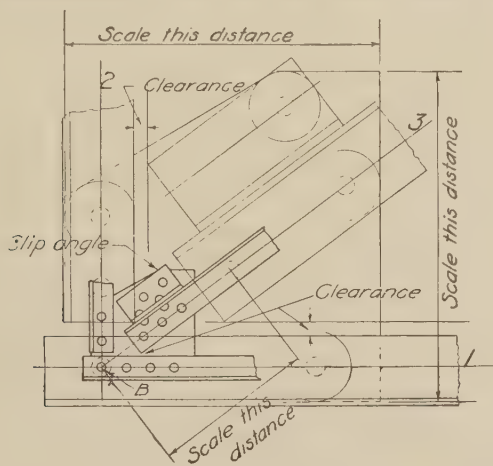


FIG. 15. Layout of joint.

the last rivets. This is done by drawing a circle of the proper radius, — equal to the specified edge distance — around the outstanding rivets in each member and then drawing the lines representing the edges of the gusset plate tangent to these circles. Gusset plates must be cut from rectangular pieces, and hence it is desirable to make as few cuts as possible to obtain the proper shape for the plates. When the gusset plates have been drawn, the truss is ready for dimensioning. The rules for dimensioning are given in a later paragraph.

**LAYOUT OF A JOINT.** — Where structural members meet at an angle other than 90 degrees, it would be a very tedious problem to determine all the necessary dimensions on the connection by calcu-



lation, unless a slope table was at hand. To avoid calculations, a layout of the joint is made to a larger scale. This may be a full-size layout, but more frequently it is made to the scale  $3'' = 1'-0''$  in light pencil lines right on the smaller scale detail drawing. The dimensions desired are then scaled off from this drawing to the nearest sixteenth of an inch.

To make such a layout, it is first necessary to draw the principal working lines of the joint as indicated by the lines marked, 1, 2, and 3 in Fig. 15, which represents a joint like *A* of the truss detailed in Fig. 5. Around these lines the members are then drawn in. For example, the bottom chord, which is a  $2\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$  angle, is laid out around line 1 by measuring down at right angles to the line a distance of  $1\frac{3}{8}''$ , which is the standard gage for the  $2\frac{1}{2}''$  leg. With the bottom line of the angle thus determined, the whole angle may now be drawn in. Then, to scale, one half inch above the top edge, draw a line for clearance. Draw the angles around the working lines 2 and 3. The proper angle for line 3 is a  $3'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$  angle and the standard gage for the  $3''$  leg is  $1\frac{3}{4}''$ . The angle may then be laid out around the working line as a gage line in the same manner as the bottom chord. The line representing the edge of the angle is extended until it intersects the clearance line of the bottom chord and at the intersection a line is drawn at right angles to line 3. This last line represents the end of the angle. The first rivet may be put in  $1\frac{1}{4}''$  from this line and then its distance to the working point *B* may be scaled and put down on the detail drawing. From the first rivet, the location of the last one may be scaled off, and a circle with a radius equal to the standard edge distance for gusset plates drawn around it. In a similar manner, the rivets farthest from the working point *B* in each member may be drawn and then the edges of the gusset plate may be drawn tangent to the edge distance circles around these rivets. Any required distance may now be scaled from this layout, and the size of the gusset plate determined. Such a layout must be made for each different joint and, although the type of connection may be quite different from the one shown, the general principle is just the same.

**SCALES.** — As has been indicated in the preceding paragraphs, two scales are frequently used in structural drafting in the same view of a detail. In this respect structural drawing departs even farther from machine drawing in that on very simple pieces as, for example, the beams shown in Figs. 9 and 16 there may be no scale

at all in one direction. Dimensions govern always and in no case is a workman permitted to scale a drawing.

The reason for the use of two scales in the detail of the truss is quite apparent, since it would be almost impossible to put in all the detail to the same scale as that employed in laying out the working lines. There would not be room to put in the dimensions where they are most required. In the case of the beams shown in Fig. 16, considerable time and money can be saved by having no scale at all or, at the most, only a scale in a vertical direction.

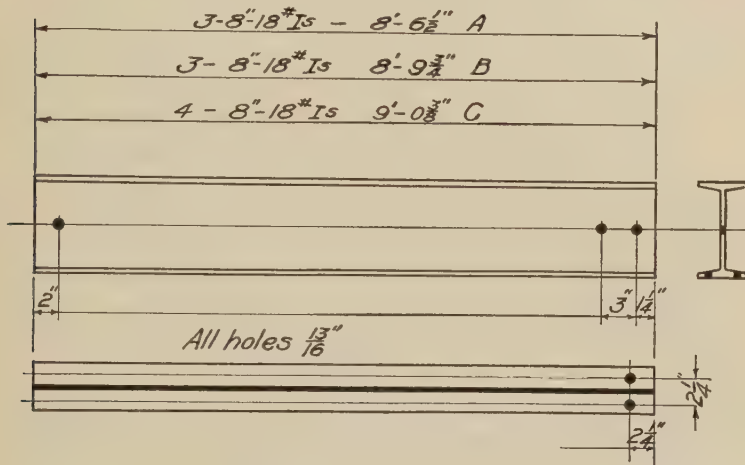


FIG. 16. Detail of floor beam.

Here three beams are detailed on one drawing just by the addition of dimension lines and notes. Many companies have printed forms showing the front, top, bottom, and end views of a beam or any combination of these views which best suits their purpose. It is only necessary for the draftsman to put in the detail and dimensions.

In structural drawing the architect's scales are the only ones employed. They range from  $\frac{1}{4}" = 1'-0"$  for laying out the working lines of large pieces to  $3" = 1'-0"$  for the layout of joints. Almost any combination between these limits may be used. The more common ones, however, are  $\frac{3}{4}" = 1'-0"$  and  $1" = 1'-0"$ .

**DIMENSIONS.** — Since a single detail may be sufficient for the fabrication of several tons of steel, it is quite evident that a single error in dimensions may spoil tons of steel, not to mention the loss

in labor and time and the loss of a reputation for reliability. Placing of the dimensions is perhaps the most difficult single problem. An examination of the illustrations in this chapter will give a basis upon which judgment can be formed as to the best placing of dimensions. The rules given apply particularly to drawings which are completely detailed in all respects. The following rules should be observed, and applied with common sense and judgment.

1. Dimension lines should be light, solid, black lines, terminating in arrows.

2. The figures should be placed **above** the dimension lines at or near the center of the space between arrows. Note. — This differs from the standard practice in machine drawing.

3. Detail dimensions should be placed in a continuous row from end to end of a member, no dimension being omitted.

4. An overall dimension should accompany each set of detail dimensions.

5. The detail dimensions should always be added to see that they check with the overall dimension.

6. Where two or more lines of dimensions are given for the same piece, they should not be placed closer together than five-sixteenths of an inch and the first line should not be closer to the piece than double this distance. It may be farther away when circumstances demand. Above all things, dimensions should not be crowded upon each other or upon the object drawn.

7. Dimensions should be calculated to the nearest sixteenth of an inch, except in the case of bevels when it is frequently advisable to work to the nearest thirty-second of an inch.

8. The work is completely detailed only when it is unnecessary for the workman to add, subtract, multiply, or perform any other mathematical operation to obtain an essential dimension.

9. Dimensions should be given as shown in *A*, Fig. 17.

10. Where a dimension line runs through a rivet whose location it does not give, the dimension line should be broken and an arc drawn around the rivet, as shown in *B*, Fig. 17. Avoid this situation whenever possible.

11. The slope of all members should be given in *run* and *rise* and not by angles. One of the dimensions of the run and rise should always be twelve inches. The run is the horizontal distance and the rise the vertical distance. See Figs. 5 and 14.

12. The division line in fractions should always be made parallel to the dimension line.

13. Before the work is submitted to the checker, it should be examined from the point of view of the shop man. All the dimensions and other information needed to lay out the work should be checked up.

14. When the space between the arrow heads is very limited, the dimension may be put in as shown in *C*, Fig. 17.

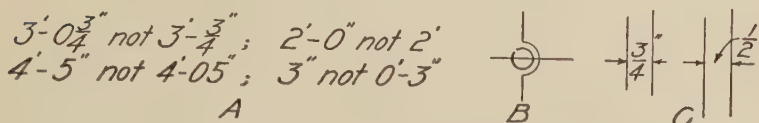


FIG. 17. Methods of dimensioning.

15. End distances are given, but edge distances are omitted. Gage lines should be dimensioned even though they are standard.

16. Field rivets should be dimensioned independently even though they are located with a series of detail dimensions.

17. The size of each piece is given close to the piece itself.

In dimensioning, as with standard details, many fabricating companies have adopted certain standard practices for their draftsmen to observe, which have been developed through experience in the shop. These vary somewhat in the various shops.

**NOTES.** — As in any other kind of drawing, notes are to be used sparingly, although nothing which will make for clearness should be omitted. The purpose of notes is two-fold, first, to make clear and definite certain information which cannot be shown by a drawing, and second, to save the draftsman's time, as, for example, where a single well-expressed note may save making another drawing quite similar to the one on which the note is made. Two kinds of notes appear on structural drawings: first, those of a general nature, as, for example, where only half of a structural member is shown, a statement to the effect that the other half is similar, or again a note specifying the size of holes to be punched, or the kind and number of coats of paint to be used; and second, those notes referring to some specific detail, as for example, a note stating that certain holes occur in a certain specified member only, or that certain holes are to be of a size different from those indicated by the general note.



The general notes are usually placed somewhere near the bottom of the sheet, under all the views of the members to which they refer, or near the title space where they will come to the notice of the shop man at his first glance. Special notes are usually placed near the parts to which they relate, and are tied up with them in some definite way. Where the note is long and the drawing is of such a complicated nature that the note cannot be placed near the part affected, it may be placed in some clear portion of the sheet and numbered or lettered. Then, at the point to which note "A" refers, the words "See Note A" may be lettered in.

Notes may be made referring to other sheets for details, but they should not refer the workman to a sheet which will in turn refer him to another sheet, to find the information he is seeking. The lettering for notes should be in the Reinhardt slant style about  $\frac{5}{32}$  of an inch high.

**TITLES.** — The title should be placed in the lower right hand corner and is preferably made in the vertical Gothic style. It should contain the name of the fabricating company, its location, the name of the company for whom the material shown is being made, together with the name of the place to which it is going. Also the usual items, such as sheet number, contract number, scale, date, drawn by, checked by, etc.

**MARKING.** — Owing to the difficulty of recognizing structural pieces in the shop, it is necessary to give all pieces some distinguishing mark by means of which they may be labeled at the time of cutting or laying out and identified for assembling after they have been properly fabricated. In addition to the assembly marks given each individual piece, an assembled part which is to be shipped and erected as a unit must also have a distinguishing mark by means of which it can be identified in the process of erection.

It is customary in many shops to use small letters and numerals for the assembly marks and reserve large capital letters for the erection marks. The assembly marks originate with the structural draftsman, whereas the erection marks are usually shown on the general plan prepared by the architect or engineer. The draftsman places the marks on each piece on his drawing and then the template maker marks his templates to correspond; finally, the layout man marks the piece of steel in the same manner. Hence the assembling crew with the drawing at hand can readily assemble the steel. Various systems of marking have been worked out in different shops; but since each shop has its own system,



only general instructions can be given. The following rules should be observed.

1. Each separate piece should be given some mark.
2. When two or more pieces are identical, they should be given the same mark and need be detailed only once.
3. When two pieces are similar in all respects except that one is left and the other right, they may be given the same mark with the suffix *R* and *L*. The one drawn is usually marked *R*.
4. The letters *i* and *l* should be avoided since it is difficult to distinguish them on a drawing or in the shop on a piece of steel. The prime mark should not be used.
5. For erection marks it is customary to use the initial letter of the name of the piece. Thus *B2* will designate a beam, while *G3* will indicate a girder, and *C2a* may designate a column.
6. Rules 1 to 4 inclusive apply to both assembling marks and also to erection marks.

**CONVENTIONAL SYMBOLS.** — The use of conventional signs and symbols is limited almost entirely to the representation of

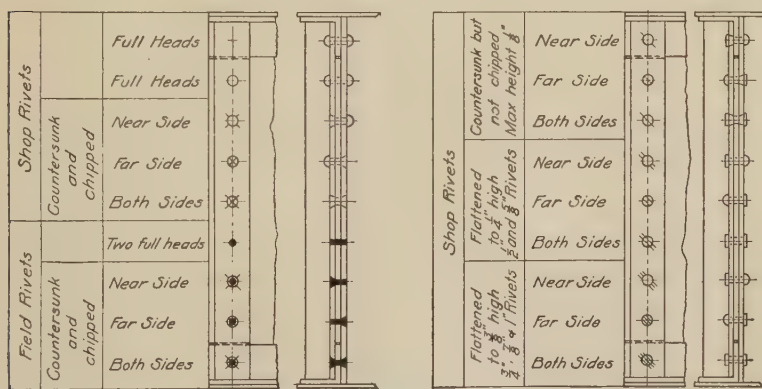


FIG. 18. Conventional rivet signs.

rivets. The standard symbols and their meaning are shown in Fig. 18. It will be noted that where the operation is to be performed on the near side or outside of the piece, the designating marks are on the outside of the circle, while to indicate the same operation on the far side or inside, the marks are on the inside of the circle.

When there is a long line of rivets uniformly spaced, all of the rivets need not be drawn in. Usually only those at the beginning

and end of a series of uniform spaces need be indicated. The side view of a rivet is not shown except when it will add to the clearness of the drawing.

A departure from the above rule must be observed in the case of field rivets. All field rivets must be shown. They are also shown in the side view unless this will confuse the drawing.

In making a bill of material or in notes, the following symbols are used as abbreviations: The I-beam is indicated by the capital letter I; the channel by a symbol similar to the cross-section of a channel lying on its back, to prevent confusion with the symbol for

|                                                                                                                            |                                                                                                 |
|----------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| <i>One I-15" x 50<sup>#</sup> x 18'-7<math>\frac{13}{16}</math>"</i>                                                       | <i>2 L<math>\angle</math>-8" x 11<math>\frac{1}{4}</math>" x 10'-6<math>\frac{3}{8}</math>"</i> |
| <i>1-15"-60<sup>#</sup> I-19'-2<math>\frac{1}{2}</math>"</i>                                                               | <i>3-8"-11<math>\frac{1}{4}</math>" L<math>\angle</math>-10'-7"</i>                             |
| <i>2 L<math>\angle</math>-4" x 3" x <math>\frac{5}{16}</math>" x 17'-6"</i>                                                | <i>2-Ts-3" x 2<math>\frac{1}{2}</math>" x 7'-2" x 4'-0"</i>                                     |
| <i>6 L<math>\angle</math> 3<math>\frac{1}{2}</math>" x 3" x <math>\frac{5}{16}</math>" x 0'-4<math>\frac{1}{2}</math>"</i> | <i>1-P1-10" x <math>\frac{3}{8}</math>" x 1'-6"</i>                                             |

FIG. 19. Methods of billing materials.

the I-beam if carelessly made, and the angle, T-bar and Z-bar are indicated in the same way by symbols representing their cross-section. The proper method of billing the various shapes is shown above. In each case the weight per foot, or thickness, in the case of the angle, must be given, as all of the structural shapes are made in several weights for the same general dimensions. See Fig. 19.

#### BIBLIOGRAPHY

- STRUCTURAL ENGINEERS' HANDBOOK, by Milo S. Ketchum. McGraw-Hill Book Company, New York, 1918.
- STRUCTURAL DRAFTING, by Carlton Thomas Bishop. John Wiley & Sons, Inc., New York, 1922.
- STRUCTURAL STEEL DRAFTING AND ELEMENTARY DESIGN, by Charles Denton Conklin. John Wiley & Sons, Inc., New York, 1915.

## CHAPTER XXI

### PATENT OFFICE DRAWINGS

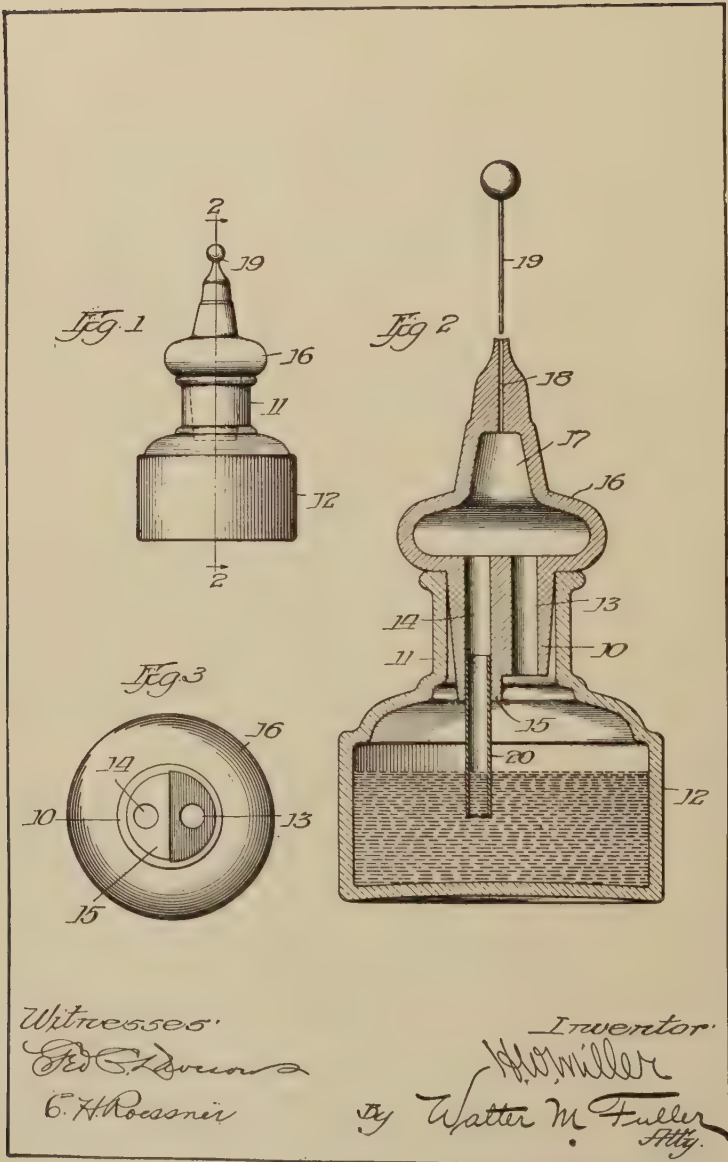
The drawings required by the Patent Office stand in a class by themselves when compared with other engineering drawings. The reason for this lies in the fact that they are drawn on one size sheet only, are reproduced by one process, have symbols quite peculiar to themselves, and in many other ways are standardized explicitly and to minute detail. Before going into these strictly drafting features of Patent Office Drawings, it may be well to point out their connection with other items entering into the successful obtaining of Letters Patent.

**APPLICATION FOR PATENTS.**<sup>1</sup> — Any person who has invented any new and useful thing or who has invented improvements on existing machines or structures may have such invention patented in the United States Patent Office within certain restrictions and in accordance with certain rules laid down by that Office. The first thing the inventor must do himself, or have an attorney do, is to file a formal application with the Commissioner of Patents. A complete application will consist of a petition, specification, oath, and initial fee of \$15, and, when required, drawings of the thing to be patented.

**Specifications.** — The specification, besides setting forth the claim or claims of the inventor to the discovery of some new thing, must contain a complete description of the thing invented, first in a general way, then in a more detailed fashion; and, if there are drawings, the description must refer to the various views by letters or numerals. No drawing should be sent to the Patent Office unless proper reference to it and description of it is made in the specification.

**Drawings.** — It is thus seen that the drawings are bound up with other necessary parts of an application for patents. The first difference between a Patent Office Drawing and any other drawing is already evident, in the fact that each view is numbered

<sup>1</sup> See Rules of Practice in the U. S. Patent Office for complete descriptions. These Rules of Practice may be secured from the Patent Office without cost, and should be obtained by anyone who is planning to secure a patent.



By courtesy of H. W. Miller.

FIG. 1. Patent office drawing.

instead of all the views of an object being grouped over one figure number. This means that the various orthographic views are not generally arranged in relation to each other in the strict formal way employed in shop drawings. The top and front views of a device might be placed on separate sheets or in any unconnected positions on the same sheet. Pictorial drawings done in ink may be submitted with an application. Figure 1 suggests the general characteristics of a Patent Office Drawing. Complete information regarding the details of making such a drawing is best obtained from the specifications for drawings, contained in sections 49 to 55, inclusive, of the Rules of Practice, which are quoted verbatim in the following paragraphs.

“49. The applicant for a patent is required by law to furnish a drawing of his invention whenever the nature of the case admits of it.

“50. The drawing may be signed by the inventor or one of the persons indicated in Rule 25, or the name of the applicant may be signed on the drawing by his attorney in fact. The drawing must show every feature of the invention covered by the claims, and the figures should be consecutively numbered, if possible. When the invention consists of an improvement on an old machine the drawing must exhibit, in one or more views, the invention itself, disconnected from the old structure, and also in another view, so much only of the old structure as will suffice to show the connection of the invention therewith.

“51. Two editions of patent drawings are printed and published — one for office use, certified copies, etc., of the size and character of those attached to patents, the work being about 6 by  $9\frac{1}{2}$  inches; and one reduction of a selected portion of each drawing for the Official Gazette.

“52. This work is done by the photolithographic process, and therefore the character of each original drawing must be brought as nearly as possible to a uniform standard of excellence, suited to the requirements of the process, to give the best results, in the interests of inventors, of the office, and of the public. The following rules will therefore be rigidly enforced, and any departure from them will be certain to cause delay in the examination of an application for letters patent:

(a) Drawings must be made upon pure white paper of a thickness corresponding to two-sheet or three-sheet Bristol board. The



surface of the paper must be calendered and smooth. India ink alone must be used, to secure perfectly black and solid lines.

(b) The size of a sheet on which a drawing is made must be exactly 10 by 15 inches. One inch from its edges a single marginal line is to be drawn, leaving the "sight" precisely 8 by 13 inches. Within this margin all work and signatures must be included. One of the shorter sides of the sheet is regarded as its top, and, measuring downwardly from the marginal line, a space of not less than  $1\frac{1}{4}$  inches is to be left blank for the heading of title, name, number, and date.

(c) All drawings must be made with the pen only. Every line and letter (signatures included) must be absolutely black. This direction applies to all lines, however fine, to shading, and to lines representing cut surfaces in sectional views. All lines must be clean, sharp, and solid, and they must not be too fine or crowded. Surface shading, when used, should be open. Sectional shading should be made by oblique parallel lines, which may be about one-twentieth of an inch apart. Solid black should not be used for sectional or surface shading. Free-hand work should be avoided wherever it is possible to do so.

(d) Drawings should be made with the fewest lines possible consistent with clearness. By the observance of this rule the effectiveness of the work after reduction will be much increased. Shading (except on sectional views) should be used only on convex and concave surfaces, where it should be used sparingly, and may even there be dispensed with if the drawing be otherwise well executed. The plane upon which a sectional view is taken should be indicated on the general view by a broken or dotted line, which should be designated by numerals corresponding to the number of the sectional view. Heavy lines on the shade sides of objects should be used, except where they tend to thicken the work and obscure letters of reference. The light is always supposed to come from the upper left-hand corner at an angle of  $45^\circ$ .

(e) The scale to which a drawing is made ought to be large enough to show the mechanism without crowding, and two or more sheets should be used if one does not give sufficient room to accomplish this end; but the number of sheets must never be more than is absolutely necessary.

(f) The different views should be consecutively numbered. Letters and figures of reference must be carefully formed. They should, if possible, measure at least one-eighth of an inch in height,

so that they may bear reduction to one twenty-fourth of an inch; and they may be much larger when there is sufficient room. They must be so placed in the close and complex parts of drawings as not to interfere with a thorough comprehension of the same, and therefore should rarely cross or mingle with the lines. When necessarily grouped around a certain part they should be placed at a little distance, where there is available space, and connected by lines with the parts to which they refer. They should not be placed upon shaded surfaces, but when it is difficult to avoid this, a blank space must be left in the shading where the letter occurs, so that it shall appear perfectly distinct and separate from the work. If the same part of an invention appear in more than one view of the drawing it must always be represented by the same character, and the same character must never be used to designate different parts.

(g) The signature of the applicant should be placed at the lower right-hand corner of each sheet, and the signatures of the witnesses, if any, at the lower left-hand corner, all within the marginal line, but in no instance should they trespass upon the drawings. (See specimen drawing, Appendix.) The title should be written with pencil on the back of the sheet. The permanent names and title constituting the heading will be applied subsequently by the office in uniform style.

(h) All views on the same sheet must stand in the same direction and must if possible stand so that they can be read with the sheet held in an upright position. If views longer than the width of the sheet are necessary for the proper illustration of the invention the sheet may be turned on its side. The space for heading must then be reserved at the right and the signatures placed at the left, occupying the same space and position as in the upright views and being horizontal when the sheet is held in an upright position. One figure must not be placed upon another or within the outline of another.

(i) As a rule, one view only of each invention can be shown in the Gazette illustrations. The selection of that portion of a drawing best calculated to explain the nature of the specific improvement would be facilitated and the final result improved by the judicious execution of a figure with express reference to the Gazette, but which must at the same time serve as one of the figures referred to in the specification. For this purpose the figure may be a plan, elevation, section, or perspective view, according to the judgment of the draftsman. All its parts should be especially

open and distinct, with very little or no shading, and it must illustrate the invention claimed only, to the exclusion of all other details. (See specimen drawing.) When well executed, it will be used without curtailment or change, but any excessive fineness, or crowding, or unnecessary elaborateness of detail will necessitate its exclusion from the Gazette.

(j) Drawings transmitted to the office should be sent flat, protected by a sheet of heavy binder's board; or should be rolled for transmission in a suitable mailing tube, but should never be folded.

(k) An agent's or attorney's stamp, or advertisement or written address will not be permitted upon the face of a drawing, within or without the marginal line.

"53. All reissue applications must be accompanied by new drawings, of the character required in original applications, and the inventor's name must appear upon the same in all cases; and such drawings shall be made upon the same scale as the original drawing, or upon a larger scale, unless a reduction of scale shall be authorized by the Commissioner.

"54. The foregoing rules relating to drawings will be rigidly enforced. A drawing not executed in conformity thereto may be admitted for purposes of examination if it sufficiently illustrates the invention, but in such case the drawing must be corrected or a new one furnished before the application will be allowed. The necessary corrections will be made by the office, upon applicant's request and at his expense. (See Rule 72.)

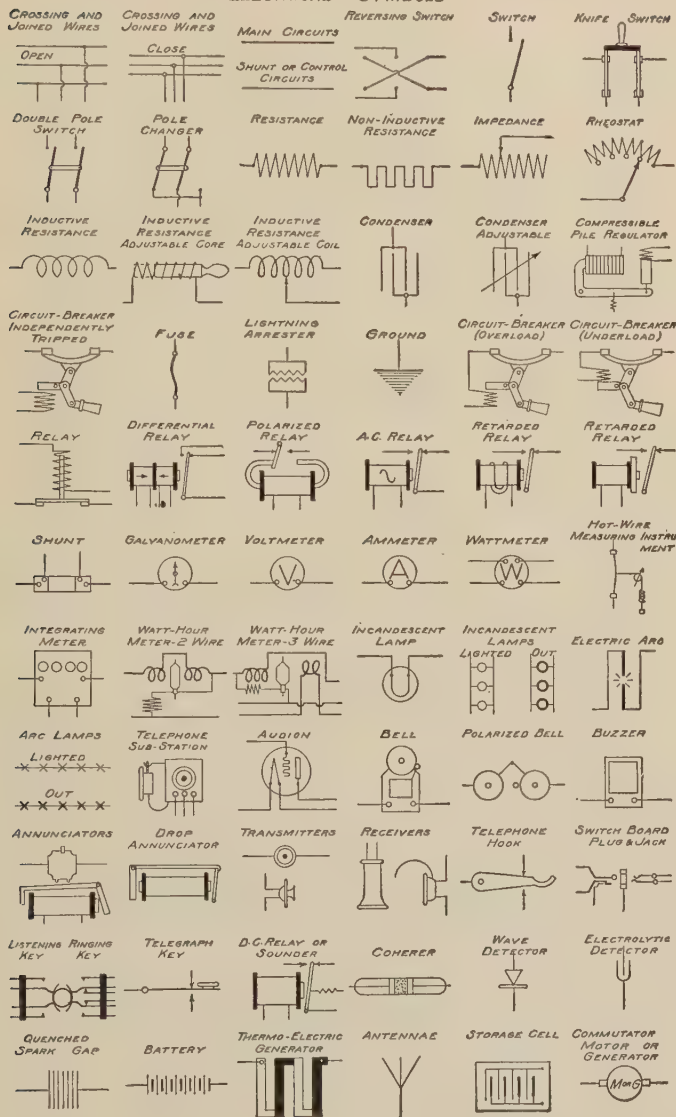
"55. Applicants are advised to employ competent draftsmen to make their drawings.

The office will furnish the drawings at cost, as promptly as its draftsmen can make them, for the applicants who cannot otherwise conveniently procure them."

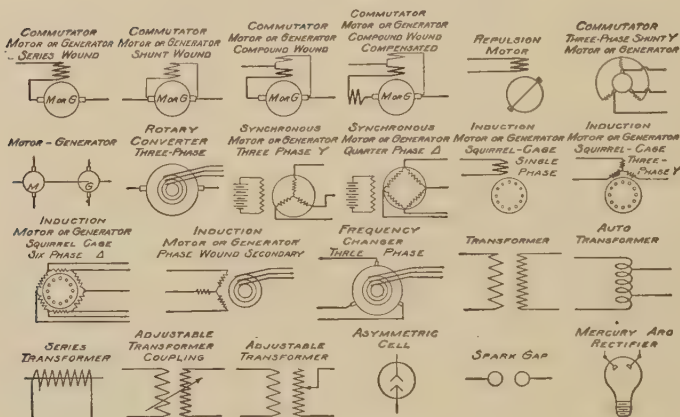
**Symbols.** — The following charts show the conventional signs and symbols adopted by the Patent Office for the guidance of draftsmen. It will be noted that in many instances they agree with those used in commercial practice, and in other instances they are distinctly different.

# UNITED STATES PATENT OFFICE SYMBOLS

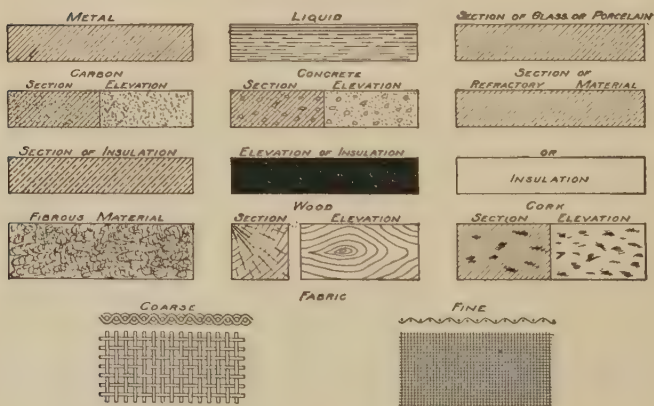
## ELECTRICAL SYMBOLS



## ELECTRICAL SYMBOLS CONTINUED



## COMMERCIAL MATERIALS



## COLORS





## CONTENTS OF APPENDIX

| SUBJECT                                                                         | PAGE     |
|---------------------------------------------------------------------------------|----------|
| <b>GEOMETRICAL CONSTRUCTIONS</b>                                                |          |
| Circles tangent to right lines and circles . . . . .                            | 301      |
| Lines tangent to curves other than circles . . . . .                            | 303      |
| Tangent to ellipse . . . . .                                                    | 303      |
| Tangent to parabola . . . . .                                                   | 304      |
| Tangent to hyperbola . . . . .                                                  | 304      |
| Tangent to any curve . . . . .                                                  | 304      |
| Conic sections                                                                  |          |
| Construction of the ellipse . . . . .                                           | 305      |
| Construction of parabola . . . . .                                              | 307      |
| Construction of hyperbola . . . . .                                             | 307      |
| Construction of rectangular hyperbola . . . . .                                 | 308      |
| Common practical curves                                                         |          |
| Construction of cycloid . . . . .                                               | 308      |
| Construction of involute . . . . .                                              | 309      |
| Construction of spiral of Archimedes . . . . .                                  | 309      |
| <b>ABBREVIATIONS</b>                                                            |          |
| <b>SYMBOLS AND CONVENTIONS</b> . . . . .                                        | 310-311  |
| Map symbols . . . . .                                                           | 312-318  |
| Electrical symbols . . . . .                                                    | 319      |
| Symbols for metals . . . . .                                                    | 320      |
| Miscellaneous symbols . . . . .                                                 | 320      |
| <b>PIPE ELEMENTS</b>                                                            |          |
| Layouts . . . . .                                                               | 321      |
| Symbols . . . . .                                                               | 322, 324 |
| Fittings . . . . .                                                              | 322, 323 |
| Tables . . . . .                                                                | 325      |
| <b>BOLT AND SCREW TABLES</b>                                                    |          |
| Sharp V-threads — diameters and threads per inch . . . . .                      | 326      |
| Elements of sharp V-threads . . . . .                                           | 326      |
| U. S. standard threads, bolts and nuts . . . . .                                | 327      |
| Hexagonal and square head cap screws . . . . .                                  | 328      |
| Flat and oval fillister head cap screws . . . . .                               | 329      |
| Button and flat countersunk head cap screws . . . . .                           | 330      |
| A. S. M. E. flat and oval fillister head machine screws . . . . .               | 331      |
| A. S. M. E. standard, flat fillister and round head machine<br>screws . . . . . | 332      |
| Standard set screws . . . . .                                                   | 333      |
| Acme standard . . . . .                                                         | 333      |

| SUBJECT                                      | PAGE    |
|----------------------------------------------|---------|
| WIRE GAGES.....                              | 334     |
| SHEET AND PLATE METAL GAGES.....             | 334     |
| RIVET SPACINGS.....                          | 335-337 |
| STANDARD STRUCTURAL DETAILS.....             | 335-337 |
| METRIC EQUIVALENT AND CONVERSION TABLES..... | 338     |
| DECIMAL EQUIVALENTS.....                     | 339     |
| NATURAL TRIGONOMETRIC TABLES.....            | 340-343 |

## APPENDIX

### GEOMETRICAL CONSTRUCTIONS

The geometrical constructions given in the following pages are for the convenience of the draftsman. It is assumed that he may use all the instruments at his disposal and that they are sufficiently accurate for all practical purposes. Thus, when he finds it necessary to erect a line perpendicular to another, he may do it with his triangles, rather than with a compass and straight edge. It is further assumed that the draftsman is familiar with the principles of plane geometry. The methods here suggested are primarily for the drafting table and therefore may not always be applicable to the laying-out floor.

#### I. — CIRCLES OF FIXED RADIUS TANGENT TO RIGHT LINES AND CIRCLES

The solution of tangency problems involving the circle depends directly upon the following definition: *the circle is the plane locus of all points a given distance from a given fixed point.* Hence, if a circle of radius  $r$  is to be tangent to a straight line, the center must be on the plane locus of all points a distance  $r$  from the line. If in addition, it is to be tangent to a circle of radius  $b$ , the center must also be on the plane locus of all points a distance  $r$  from this circle. The intersection of these two loci gives a point which satisfies both conditions

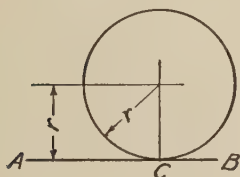


FIG. 1.

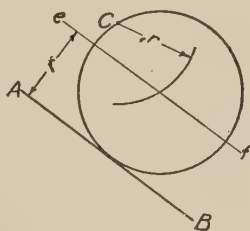


FIG. 2.

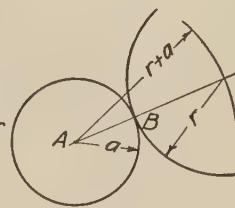


FIG. 3.

and locates the center of the required circle. By thinking along these lines, the reason for each step in the following constructions can be readily discovered.

**Problem 1.** — To find the center of a circle of fixed radius  $r$  tangent to a right line  $AB$  at a given point  $C$  upon it. See Fig. 1.

**Construction.** — At  $C$  erect a perpendicular to the line  $AB$  and on this perpendicular measure off the distance  $r$ , which locates the required center,

Problem 2. — To find the center of a circle of fixed radius  $r$  tangent to a given right line  $AB$  and passing through a point  $C$  not on the line. See Fig. 2.

Construction. — At a distance  $r$  from the line  $AB$  draw a line parallel to it. With  $C$  as a center and radius  $r$  draw an arc intersecting the line just drawn. The intersection is the required center.

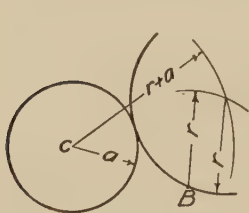


FIG. 4.

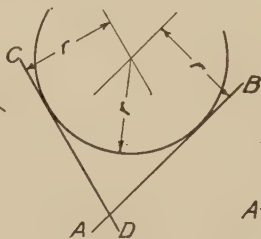


FIG. 5.

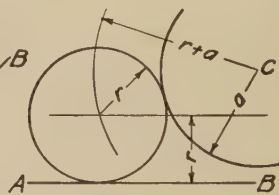
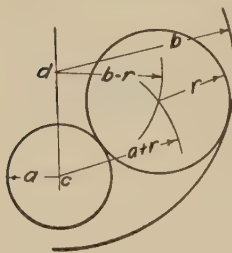


FIG. 6.

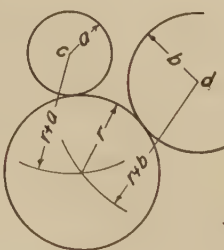
Problem 3. — To find the center of a circle of fixed radius  $r$  tangent to another circle of radius  $a$  at a point  $B$  upon it. See Fig. 3.

Construction. — Draw a line from the center through the point  $B$ , and then with  $A$  as a center and radius  $r + a$  describe an arc intersecting the line. The intersection is the required center.

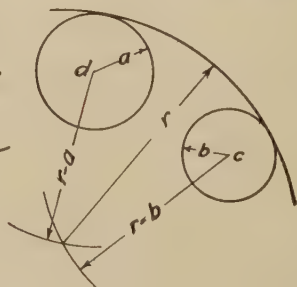
Problem 4. — To find the center of a circle of fixed radius  $r$  tangent to another circle of radius  $a$  and passing through a point  $B$  outside the circle. See Fig. 4.



A



B



C

FIG. 7.

Construction. — With center  $c$  and radius  $r + a$  describe an arc, and then with  $B$  as a center and  $r$  as a radius describe another arc intersecting the first. This intersection is the required center.

Problem 5. — To find the center of a circle of fixed radius  $r$  tangent to two intersecting right lines  $AB$  and  $CD$ . See Fig. 5.

Construction. — Draw lines parallel to  $AB$  and  $CD$  at a distance  $r$  from each. The intersection of these lines is the required center.

Problem 6. — To find the center of a circle of fixed radius  $r$  tangent to a right line  $AB$  and to another circle of radius  $a$ . See Fig. 6.

Construction. — Draw a line parallel to  $AB$  a distance  $r$  from it. With  $c$  as

a center and  $r + a$  as a radius describe an arc. The intersection of the arc and straight line locates the required center.

Problem 7. — To find the center of a circle of fixed radius  $r$  tangent to two other circles of radius  $a$  and  $b$  respectively. See Fig. 7,  $A$ ,  $B$  and  $C$ . Several cases arise in this problem, three of which have been shown in the Figure 7.

Construction A. — With  $d$  as a center and  $b - r$  as a radius describe an arc, and then with  $c$  as a center and  $a + r$  as a radius describe an arc. The intersection of the two arcs locates the required center.

Construction B. — With  $c$  as a center and  $r + a$  as a radius describe an arc, and then with  $d$  as a center and  $r + b$  as a radius describe another arc which will intersect the first, thus giving the required center.

Construction C. — With  $c$  as a center and  $r - b$  as a radius describe an arc, and then with  $d$  as a center and  $r - a$  as a radius describe another arc intersecting the first. The intersection is the required center.

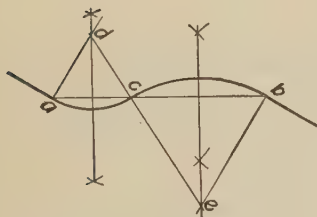


FIG. 8.

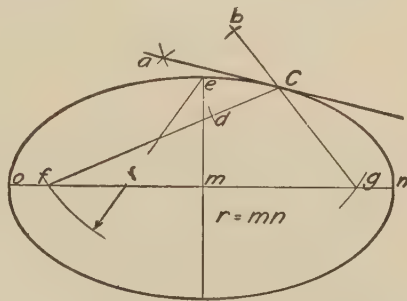


FIG. 9.

Problem 8. — To find the centers of two circles which will connect two parallel right lines by a reverse curve. See Fig. 8.

Construction. — Select the points  $a$  and  $b$  at which the curve is to join the parallel lines, and connect them by a straight line. Choose the point  $c$  at which it is desired the curve shall cross the line  $ab$ . At  $a$  and  $b$  erect perpendiculars to the two parallel lines. Erect perpendicular bisectors of the lines  $ac$  and  $bc$ . The intersection of the bisectors and the perpendiculars from  $a$  and  $b$  locates the centers  $d$  and  $e$ .

## II. — LINES TANGENT TO CURVES OTHER THAN THE CIRCLE

Problem 9. — To draw a tangent to an ellipse at a given point  $C$  upon it. See Fig. 9.

Construction. — With either end of the minor axis as a center and a radius  $r$  equal to one half the major axis, draw arcs intersecting the major axis. The points of intersection locate the foci  $f$  and  $g$  of the ellipse. From the foci draw lines  $fC$  and  $gC$ . Bisect the angle  $fCb$ . The bisector  $aC$  is the required tangent.

Problem 10. — To draw a tangent to a parabola at any given point  $C$  upon it. See Fig. 10.

Construction. — From the given point  $C$  draw a line perpendicular to the



directrix, and a second line to the focus. The bisector of the angle between these lines is the required tangent.

Problem 11. — To draw a line tangent to an hyperbola at a given point  $C$  upon it. See Fig. 11.

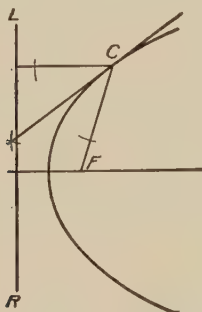


FIG. 10.

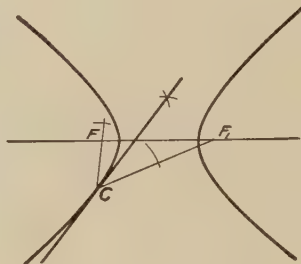


FIG. 11.

Construction. — Draw a line from the point  $C$  to each of the foci  $F$  and  $F_1$ . The bisector of this angle is the required tangent.

Problem 12. — To draw a line tangent to any given curve at any given point  $O$  upon it. See Fig. 12.

Construction. — Assume any curve  $AOC$ , to which a line is to be drawn tangent at the point  $O$ . With  $O$  as a center draw an arc  $hx$  of any convenient radius. Draw a number of secants from the point  $O$  to each side of the curve as shown. From the point  $h$  on the secant  $Oa$  extended, lay off the distance  $hk$  equal to  $Oa$ . Proceed in like manner with each secant, laying off those distances on the one side of  $O$  on the corresponding side of the arc as is  $hk$ , and those on the other side of  $O$  on the opposite side of the arc. Through the points thus obtained draw a smooth curve. The intersection of this curve with the arc locates a second point on the tangent. Proof of this method depends upon the proposition that the tangent is the limiting position of the secant.

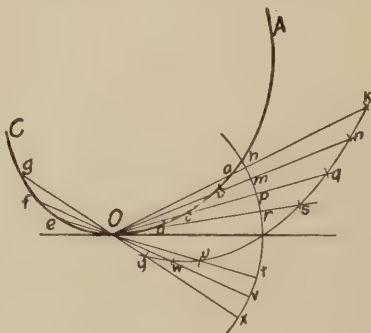


FIG. 12.

### III. — THE CONIC SECTIONS

The term conic section is applied to a group of curves which are formed by the intersection of a plane and the surface of a cone. If we assume a right circular cone, we may pass a plane through it in five distinctive positions, four of which give the curves referred to as conic sections, as shown in the small drawings of Fig. 13.

1. If a plane is passed through the vertex of the cone so that it cuts the cone, it will cut right lines from the surface.
2. If a plane is passed through the cone at right angles to the axis at any point other than the vertex, it will cut circles from the surface.
3. If a plane is passed through the cone at an angle with the axis and not parallel to an element, it will cut an ellipse from the surface.
4. If a plane is passed through the cone parallel to an element and perpendicular to the plane of the axis and the element, it will cut a parabola from the surface.

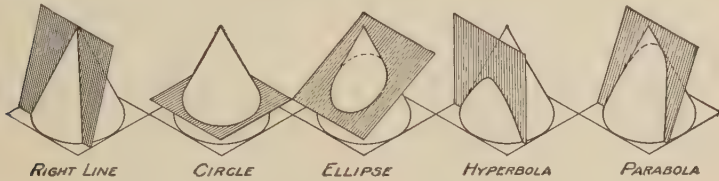


FIG. 13.

5. If a plane is passed through the cone parallel to the axis, it will cut an hyperbola from the surface.

Problem 13. — To construct any conic section. See Fig. 13.

Construction. — Any of these curves might be constructed by assuming a right circular cone and finding the intersection of a properly placed plane with its surface, as pictured in isometric in the figure, and explained in Section 2 of Chapter VII. Such constructions are laborious and properly belong in the realm of Descriptive Geometry. Several shorter and more practical methods for constructing the curves are given below.

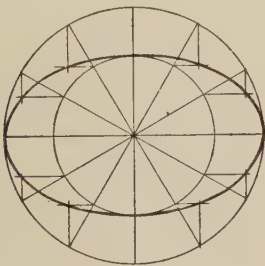


FIG. 14.

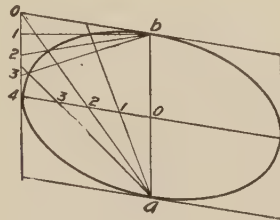


FIG. 15.

**ELLIPSE.** — An ellipse is the plane locus of all points the sum of whose distances from two fixed points, called the foci, is a constant.

Problem 14. — Given the major and minor axes of an ellipse, to construct the ellipse. See Fig. 14.

Construction. — Draw two concentric circles with diameters corresponding to the major and minor axes. Draw a line from the center crossing both circles. At the intersection of this line with the small circle draw a line parallel to the major axis, and from the intersection with the large circle draw a line parallel to

the minor axis. The intersection of these two lines locates a point on the ellipse. Twelve or more points, equally spaced around the circles, should be found in the same way to make an accurate ellipse. The ellipse must, of course, be drawn with an irregular curve in the usual way.

Problem 15. — Given the conjugate axes of an ellipse, to construct the ellipse. See Fig. 15.

Construction. — Upon the given conjugate axes construct a rhomboid which will enclose the ellipse. Divide the major conjugate axis into any number of equal parts and make a similar division in the short side of the rhomboid. The intersection of corresponding lines,  $a - 1$  and  $b - 1$ , for example, locate points on the ellipse.

Problem 16. — (Approximate Method). Given the major and minor axes, to construct the ellipse. See Fig. 16.

Construction. — Four center method. Draw the rectangle  $mno p$  which will enclose the ellipse. Draw the line  $dg$ . Lay off on it the distance  $df$  equal to  $cb$ , equal to half the difference between the major and minor axes. Erect a per-

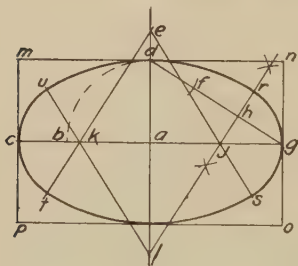


FIG. 16.

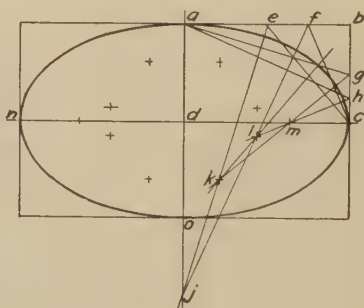


FIG. 17.

pendicular bisector of the remaining portion  $fg$ . The intersection of this bisector with the major and minor axes locates the centers  $l$  and  $j$ . The intersection of the perpendicular bisector from the opposite side locates the centers  $k$  and  $e$ .

Problem 17. — (Approximate method.) Given the major and minor axes, to construct the ellipse. See Fig. 17.

Construction. — Twelve center method. Draw the rectangle  $abcd$ . Divide  $ab$ ,  $eb$ ,  $bc$ , and  $gc$  in halves. Draw line  $ag$  and from  $e$  draw a perpendicular to it. Locate the intersection of this line with the minor axis produced. Draw line  $ec$  and from  $g$  draw a perpendicular to it till it intersects  $ej$  at  $k$ . Draw line  $ah$  and from  $f$  erect a perpendicular to it. Draw the line  $fe$  and from  $h$  erect a perpendicular to it until it intersects  $fj$  at  $l$ . Draw the line  $kl$  of sufficient length to cross the ellipse when drawn. The points  $j$ ,  $k$ ,  $l$ , and  $m$  are the centers for one-fourth of the ellipse. Locate the remaining centers in symmetrical positions around the axes by any convenient method. The centers thus found, if carefully worked out, will approximate very closely an ellipse of any size and ratio of axes. When the major and minor axes approach each other in length, the centers  $k$  and  $l$  may be omitted.

**PARABOLA.** — The parabola is the plane locus of all points which are equidistant from a given fixed point, called the focus, and a given fixed line, called the directrix.

**Problem 18.** — Given the width  $AB$  and the depth  $BC$ , of a parabola, to draw the parabola. See Fig. 18.

**Construction.** — Draw the rectangle  $ABCD$  which will enclose the part of the curve desired. Divide the short side of the rectangle into any number of parts and the long side into twice that number, as shown in the figure. Through

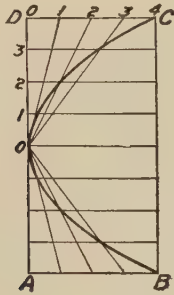


FIG. 18.

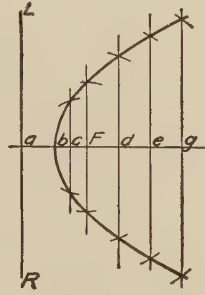


FIG. 19.

the divisions on the long side, draw lines parallel to the short side, and from the center of the long side draw lines to the consecutive divisions of the short side. The intersections of the lines  $0-1$  and  $1, 0-2$  and  $2$  locate points on the curve.

**Problem 19.** — Given the directrix and the focus, to draw the parabola. See Fig. 19.

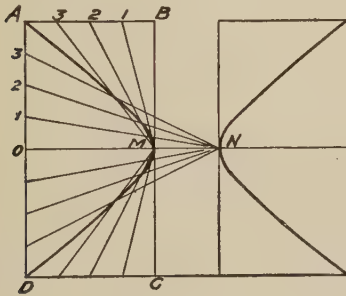


FIG. 20.

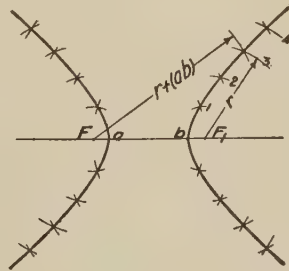


FIG. 21.

**Construction.** — This construction follows directly from the definition of the parabola. Draw the axis through  $F$  perpendicular to  $LR$ . Bisect the line  $aF$ . Through any convenient points  $c, d, e$ , and  $g$  draw lines parallel to  $LR$ . With  $F$  as a center and radii successively equal to  $ac, ad, ae$ , and  $ag$  strike arcs intersecting the corresponding parallel lines through  $c, d, e$ , and  $g$ . These points determine the parabola.

**HYPERBOLA.** — The hyperbola is the plane locus of all points the difference of whose distances from two fixed points, called the foci, is a constant.

**Problem 20.** — Given the width and depth of a portion of the hyperbola, to draw the hyperbola. See Fig. 20.

**Construction.** — Draw the rectangle  $ABCD$  to enclose the portion of the curve desired. Another rectangle which will enclose the other limb should also be drawn. Divide the short side of the rectangle into any number of equal parts and the long side into double that number of equal parts. From the point  $M$  draw lines to the divisions on the short side and from the point  $N$  on the other rectangle draw lines to the divisions on the long side. The intersection of the corresponding lines  $M-1$  and  $N-1$ , etc., locate points on the curve.

**Problem 21.** — Given the two foci, to draw the hyperbola. See Fig. 21.

**Construction.** — With  $F_1$  as a center draw the arcs 1, 2, 3, etc., at any convenient distance. Then, with  $F$  as a center draw arcs intersecting the arcs 1, 2, 3, etc. The radii of the arcs last drawn shall be equal to the former plus the distance  $ab$ , in each case. The points of intersection determine the curve.

**RECTANGULAR HYPERBOLA.** — This curve has far greater practical application than the other forms of the hyperbola, in that it always occurs in the study of laws governing the expansion of any gas.

**Problem 22.** — Given the location of one point  $A$  on the curve in rectangular coördinates, to draw the hyperbola. See Fig. 22.

**Construction.** — Draw the ordinate and abscissa through the point. Divide the ordinate into any number of parts and draw diagonals from the origin  $O$  through these points until they cross the abscissa through the point  $A$ . Draw horizontal lines through the intersections of the diagonals with the ordinate through  $A$  and vertical lines through the intersections of the diagonals with the abscissa through  $A$ . The intersections of these horizontal and vertical lines give points on the curve.

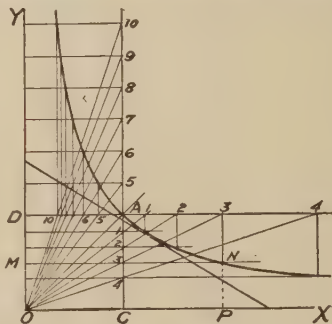


FIG. 22.

#### IV. — COMMON CURVES IN PRACTICAL WORK

**CYCLOIDS.** — The cycloids form a group of curves generated by the path of a fixed point on the circumference of a rolling circle. When the circle rolls on a straight line, the path of the point is called simply a cycloid. If the circle rolls on the outside of another circle the path of the point is called an epicycloid, whereas if the circle rolls on the inside of another circle the path of the point is called a hypocycloid. These curves have a practical application in the design of gear teeth.

**Problem 23.** — To draw the cycloid. See Fig. 23.

**Construction.** — Divide the rolling circle into twelve or more equal parts and lay out on the straight line twelve divisions equal to the arcs of the circle. As the circle rolls along, the center will occupy successively the positions 1, 2, 3, etc., while the point on the circumference will rise to the elevation on the hori-



zontal lines *a, b, c, d, etc.* The intersections of the circle in its successive positions with the horizontal lines will give the required points.

Problem 24. — To draw the epicycloid and the hypocycloid. See Fig. 24.

Construction. — The construction of the epicycloid and hypocycloid are quite similar to each other and can be readily grasped from the figure. Note that in both cases there is a separate line of centers for the rolling circles and in place of the horizontal lines *a, b, c, etc.*, we have the arcs *a, b, c*, and so on.

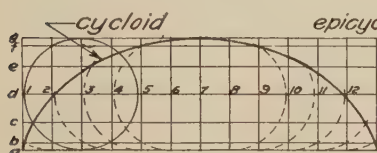


FIG. 23.

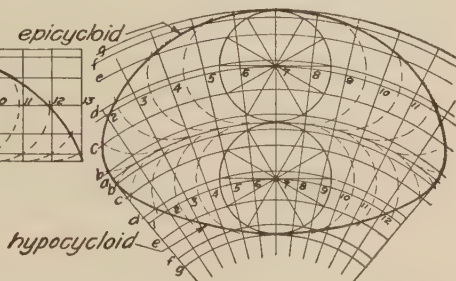


FIG. 24.

**INVOLUTE.** — The involute is another curve which also has a practical application in the design of gear teeth. It may, perhaps, be most clearly defined as the path described by the end of a string as it is unwound from a cylinder. It may be constructed on this principle.

Problem 25. — To draw the involute. See Fig. 25.

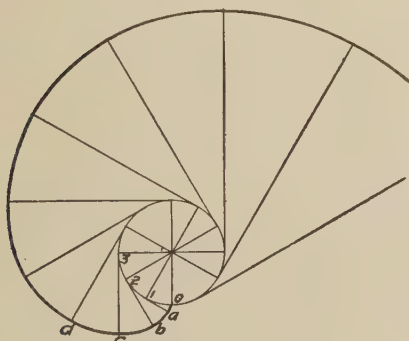


FIG. 25.

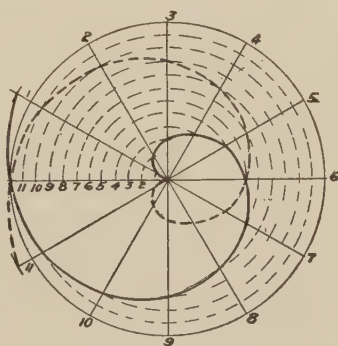


FIG. 26.

Construction. — Divide the circle which is the intersection of a cylinder with the plane of the curve, into twelve or more equal parts. Then, beginning at any convenient point, draw tangents to the circle at the points of division and on each of these tangents lay off a length equal to the length of the arc from the point of beginning to the tangent point. Thus the line *Sc* is equal in length to the arc *o3*. The points thus obtained locate the curve.

**SPIRAL OF ARCHIMEDES.** — In the spiral of Archimedes, the radius of curvature increases directly as the angle through which it rotates. We may

assume an arbitrary amount by which the radius shall increase in passing through a certain angle.

Problem 26. — To draw the spiral of Archimedes. See Fig. 26.

Construction. — With any convenient point as a center, draw a circle and divide into twelve equal parts. Divide the radius into the same number of equal parts. One of the divisions of the radius is then the increment by which the radius of curvature increases in passing through an angle of 30 degrees. Then beginning at the center and intersecting radius 1 by arc 1, and radius 2 by arc 2, and so on, twelve points on the curve can be found. The curve thus generated is commonly used in cam design.

## ABBREVIATIONS

### METALS

|                        |          |                        |          |
|------------------------|----------|------------------------|----------|
| Aluminum.....          | Almn.    | Lead.....              | Lead     |
| Babbitt.....           | Bb.      | Malleable iron.....    | M. I.    |
| Brass.....             | B.       | Open hearth steel..... | O. H. S. |
| Bronze.....            | Bz.      | Phosphor bronze.....   | Ph. Bz.  |
| Carbon.....            | Cbn.     | Steel.....             | Steel    |
| Cast brass.....        | C. B.    | Steel casting.....     | S. C.    |
| Cast copper.....       | C. Cop.  | Wrought iron.....      | W. I.    |
| Cast iron.....         | C. I.    | Zinc.....              | Zn.      |
| Cast steel.....        | C. S.    | Tool steel.....        | T. S.    |
| Cold rolled steel..... | C. R. S. | Forged tool steel..... | F. T. S. |
| Copper.....            | Cop.     | High speed steel.....  | H. S. S. |

### MECHANICAL & ELECTRICAL

|                               |          |                       |          |
|-------------------------------|----------|-----------------------|----------|
| Horsepower.....               | H. P.    | Kilowatt.....         | K. W.    |
| Brake horsepower.....         | B. H. P. | Kilowatt hour.....    | K. W. H. |
| British thermal unit.....     | B. T. U. | Kilo-volt-ampere..... | K. V. A. |
| Indicated horsepower.....     | I. H. P. | Ampere.....           | Amp.     |
| Mean effective pressure... .. | M. E. P. | Transformer.....      | Trans.   |
| Revolutions per minute... ..  | R. P. M. | Generator.....        | Gen.     |

### GAGES

|                                                     |          |
|-----------------------------------------------------|----------|
| Brown & Sharpe, or American Standard Wire Gage..... | B. & S.  |
| Birmingham, or Stubs Iron Wire Gage.....            | B. W. G. |
| National, or Roebbling's, or Washburn & Moen's..... | N. W. G. |
| Music Wire Gage.....                                | M. W. G. |
| United States Gage.....                             | U. S. G. |
| Twist Drill & Steel Wire Gage.....                  | T. D. G. |
| Stubs' Steel Wire Gage.....                         | S. W. G. |

## GENERAL

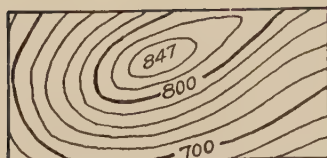
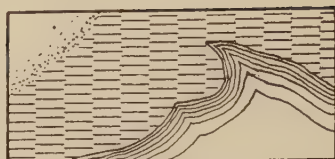
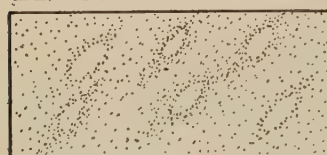
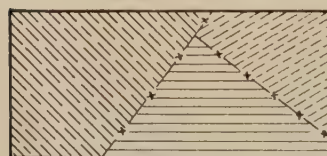
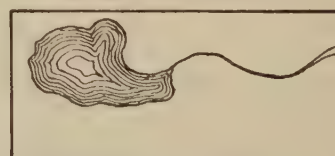
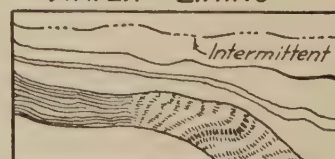
|                    |            |                    |          |
|--------------------|------------|--------------------|----------|
| Building.....      | Bldg.      | General.....       | Gnl.     |
| Case harden.....   | C. H.      | Inch, inches.....  | In. or " |
| Center.....        | Cr.        | Machine.....       | Mach.    |
| Center line.....   | C. L.      | Manufacturing..... | Mfg.     |
| Circumference..... | Circum.    | Maximum.....       | Max.     |
| Company.....       | Co.        | Minimum.....       | Min.     |
| Counterbore.....   | Cbr.       | Specification..... | Spec.    |
| Countersink.....   | Csk.       | Square.....        | Sq.      |
| Cylinder.....      | Cyl.       | Standard.....      | Std.     |
| Diameter.....      | dia. or D. | Threads.....       | Thds.    |
| Drawing.....       | Dwg.       | Weight.....        | Wgt.     |
| Foot, feet.....    | ft. or '   | Finish.....        | f.       |

---

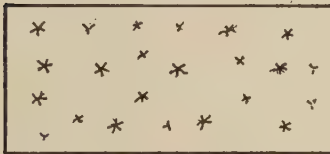
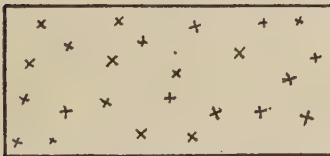
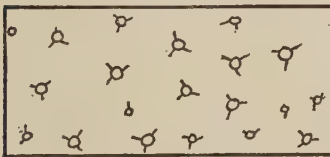
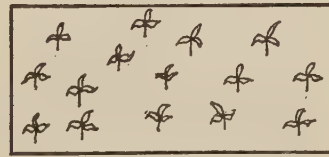
### Symbols and Conventions

As civilization progresses and science and industry combine to produce new devices and appliances — some simple and easy to represent in both the spoken and graphical language, others intricate and well-nigh impossible of description or graphical representation — it becomes necessary to adopt symbols or conventional representations, so-called, to allow of quick and easy drawing of these generally used agencies in industry. Qualities of color, kind and texture of materials, as well as the shape of many things, are easily symbolized. Symbols and conventions are to drawing what idioms are to written composition. They are signs that are full of meaning because of what they connote and suggest, rather than because of any direct likeness to the thing they represent.

The use of the terms "conventional drawing," and "conventions" has been general throughout this text. Many symbols and conventions have been included with the text material of a number of chapters. Such for instance are the chapters on Working Drawings, Structural, Architectural, Map, and Patent Office Drawing. The wide scope of the draftsman's domain prevents any text of this kind from fully treating of the various fields in which he may need to work. Even the mention of some specialized topics has been impossible. The following pages, therefore, have been set aside for the presentation of the more important symbols used in different fields of engineering drawing not treated of elsewhere. They should be studied with the idea of fixing in the mind the fact that there are well-standardized symbols in this or that field of drafting, rather than of attempting to memorize any individual symbol which one may observe.

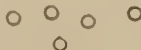
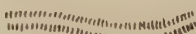
*CONTOURS**MUD FLATS**DEPRESSION CONTOURS**TIDAL FLATS**SAND DUNES**FRESH MARSH**BLUFFS**SALT MARSH**CULTIVATED GROUND**WATER LINING**SHORE LINE**STREAM, FALLS & RAPIDS*

Topographical symbols; first column brown, second column blue ink.

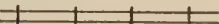
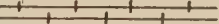
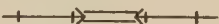
*GRASS**TROPICAL GRASS**WOODS (BROAD LEAF)**ORCHARD**PINE (NARROW LEAF)**PALM TREES**BAMBOO**PALMETTO**CACTUS**BANANA**COTTON**RICE*

Topographical symbols; green ink.

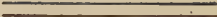
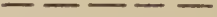


*BUILDINGS IN GENERAL* ■ *TO SCALE**RUINS**CHURCH**HOSPITAL**SCHOOLHOUSE**POST OFFICE**TELEGRAPH OFFICE**WATERWORKS**WINDMILL**GEMETERY**CITY TOWN OR VILLAGE**MINE OR QUARRY**PROSPECT**SHAFT**MINE TUNNEL* Opening  
Showing direction*OIL WELLS**OIL TANKS**COKE OVENS**LEVEE*

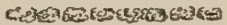
Topographical symbols; black ink.

|                          |                            |                                                                                     |
|--------------------------|----------------------------|-------------------------------------------------------------------------------------|
| <i>ROAD</i>              | <i>Metaled</i>             |    |
| <i>ROAD</i>              | <i>GOOD</i>                |    |
| <i>ROAD</i>              | <i>POOR OR PRIVATE</i>     |    |
| <i>TRAIL OR PATH</i>     |                            |    |
| <i>STEAM RAILROAD</i>    | <i>SINGLE TRACK</i>        |    |
| "                        | " <i>DOUBLE TRACK</i>      |    |
| "                        | " <i>TWO TRACKS</i>        |    |
| "                        | " <i>IN STREET OR ROAD</i> |    |
| "                        | " <i>TUNNEL</i>            |    |
| "                        | " <i>STATION</i>           |    |
| <i>ELECTRIC RAILROAD</i> | <i>SINGLE TRACK</i>        |    |
| "                        | " <i>DOUBLE TRACK</i>      |  |
| "                        | " <i>IN STREET</i>         |  |
| <i>TELEGRAPH LINE</i>    |                            |  |
| "                        | " <i>ALONG ROAD</i>        |  |
| "                        | " <i>ALONG TRAIL</i>       |  |
| <i>POWER LINE</i>        |                            |  |

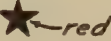
Topographical symbols; black ink.

|                                |                                                                                     |
|--------------------------------|-------------------------------------------------------------------------------------|
| CANAL                          |    |
| DRAINAGE OR IRRIGATION DITCH   |    |
| AQUEDUCT                       |    |
| WATER PIPE                     |    |
| AQUEDUCT TUNNEL                |    |
| CANAL LOCK                     |    |
| BRIDGE HIGHWAY                 |    |
| " RAILROAD                     |    |
| DRAW BRIDGE HIGHWAY            |    |
| " " RAILROAD                   |    |
| TRUSS BRIDGE (W=WOOD, S=STEEL) |    |
| FOOT BRIDGE                    |    |
| SUSPENSION BRIDGE              |  |
| ARCH BRIDGE                    |  |
| PONTOON BRIDGE                 |  |
| FERRY                          |  |
| FORD (INFANTRY OR CAVALRY)     |  |
| FORD (WAGON OR ARTILLERY)      |  |
| DAM                            |  |

Topographical symbols; color as marked.

|                                                                            |                                                                                     |
|----------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| NATIONAL, STATE, OR PROVINCE LINE                                          |    |
| COUNTY LINE                                                                |    |
| CIVIL TOWNSHIP DISTRICT, OR PRECINCT                                       |    |
| RESERVATION LINE                                                           |    |
| LAND GRANT LINE                                                            |    |
| CITY VILLAGE OR BOROUGH                                                    |    |
| CEMETERY, SMALL PARK,                                                      |    |
| TOWNSHIP, SECTION AND QUARTER SECTION LINES                                |    |
| { Any one for Township line alone, any two for Township and section lines. |                                                                                     |
| TOWNSHIP AND SECTION CORNERS RECOVERED                                     |    |
| BOUNDARY MONUMENT                                                          |    |
| TRIANGULATION STATION                                                      |    |
| BENCH MARK                                                                 |   |
| U.S. MINERAL MONUMENT                                                      |  |
| BOARD OR ANY KIND                                                          |  |
| WORM                                                                       |  |
| FENCES WIRE { BARBED                                                       |  |
| SMOOTH                                                                     |  |
| STONE                                                                      |  |
| HEDGE                                                                      |  |

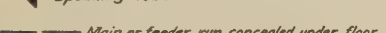
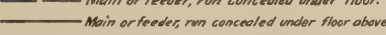
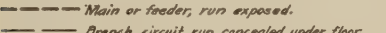
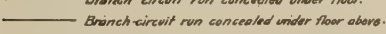
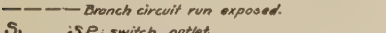
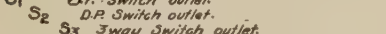
Topographical symbols; black ink.

|                                                                   |                                                                                     |
|-------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| AVIATION PARK OR LANDING PLACE                                    |    |
| GAS TANKS                                                         |    |
| GASOLINE SERVICE STATIONS                                         |    |
| MOTOR REPAIR SHOPS                                                |    |
| HANGARS FOR DIRIGIBLES                                            |    |
| AERODROMES                                                        |    |
| CHURCHES                                                          |    |
| PROMINENT BUILDINGS                                               |    |
| WINDMILLS <i>To be shown only in<br/>sparsely settled country</i> |    |
| FACTORY CHIMNEYS                                                  |    |
| SIGNAL LIGHTS                                                     |    |
| ISOLATED TREES                                                    |   |
| STAND PIPES                                                       | <i>To be shown only in<br/>sparsely settled country</i>                             |
| WATER TANKS                                                       |                                                                                     |
| STEEL TOWERS AND TRANSMISSION LINES                               |  |
| PROMINENT PEAKS                                                   |  |
| OIL WELL TOWERS                                                   |  |
| COLUMNS AND MONUMENTS                                             |  |
| AVIATION FIELDS                                                   | <i>red letters</i> <b>CHANUTE</b>                                                   |

Aeronautical map symbols; black ink.



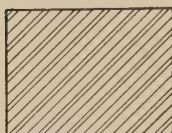
## ELECTRIC WIRING SYMBOLS

|                                                                                     |                                                                                                                                    |                                                                                     |                                                                                                                                                             |
|-------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
|    | Ceiling outlet, Electric only. Numeral in center indicates No. of Std. 16 C.P. lamps..                                             |    | Ceiling Fan Outlet.                                                                                                                                         |
|    | Ceiling outlet, Combination. $\frac{4}{16}$ indicates 4-16 C.P. Std. incandescent lamps and 2 Gas burners..                        |    | Distribution Panel.                                                                                                                                         |
|    | Ceiling outlet, Gas only.                                                                                                          |    | Junction or Pull box.                                                                                                                                       |
|    | Bracket outlet, Electric only. Numeral in center indicates No. of Std. 16 C.P. incandescent lamps.                                 |    | Motor Control Outlet.                                                                                                                                       |
|    | Bracket outlet, Combination. $\frac{4}{16}$ indicates 4-3 Std. 16 C.P. incandescent lamps and 2 Gas burners..                      |    | Motor Outlet. Numeral in center = H.P.                                                                                                                      |
|    | Bracket outlet, Gas only.                                                                                                          |    | Transformer                                                                                                                                                 |
|    | Wall or baseboard receptacle outlet. Numeral in center indicates number of Std. 16 C.P. incandescent lamps.                        |    | Watchman clock outlet.                                                                                                                                      |
|    | Floor outlet. Numeral in center indicates number of Std. 16 C.P. incandescent lamps.                                               |    | Master Time Clock outlet.                                                                                                                                   |
|    | Outlet for outdoor standard or pedestal, electric only. Numeral indicates number of Std. 16 C.P. incandescent lamps.               |    | Secondary Time clock outlet.                                                                                                                                |
|    | Drop cord outlet.                                                                                                                  |    | Watchman Station outlet.                                                                                                                                    |
|    | Outlet for outdoor standard or pedestal, Combination. $\frac{6}{3}$ indicates 6 Std. 16 C.P. incandescent lamps and 3 Gas burners. |    | Door opener.                                                                                                                                                |
|    | One lamp outlet, for lamp receptacle.                                                                                              |    | Special outlet, for signal systems.                                                                                                                         |
|    | Ara lamp outlet.                                                                                                                   |    | Battery outlet.                                                                                                                                             |
|    | Special outlet, for lighting, heating and power current, as described in specifications                                            |    | Meter outlet                                                                                                                                                |
|    | Telephone outlet, private service.                                                                                                 |    | Bell outlet                                                                                                                                                 |
|   | Telephone outlet, public service.                                                                                                  |   | Buzzer outlet                                                                                                                                               |
|  | Annunciator. Numeral indicates no. of points.                                                                                      |  | Push Button outlet, Numeral indicates the number of buttons.                                                                                                |
|  | Speaking tube.                                                                                                                     |  | Circuit for clock, telephone, bell or other service, run under floor, concealed. Kind of service, ascertained by symbol to which line connects.             |
|  | Main or feeder, run concealed under floor.                                                                                         |  | Circuit for clock, telephone, bell or other service, run under floor above, concealed. Kind of service wanted ascertained by symbol to which line connects. |
|  | Main or feeder, run concealed under floor above.                                                                                   |  | Pole line.                                                                                                                                                  |
|  | Main or feeder, run exposed.                                                                                                       |  | Riser                                                                                                                                                       |
|  | Branch circuit run concealed under floor.                                                                                          |  | 4-way switch outlet.                                                                                                                                        |
|  | Branch circuit run concealed under floor above.                                                                                    |  | Automatic Door switch outlet.                                                                                                                               |
|  | Branch circuit run exposed.                                                                                                        |  | Electrolux switch outlet.                                                                                                                                   |
|  | S1 S.P. switch outlet.                                                                                                             |                                                                                     |                                                                                                                                                             |
|  | S2 D.P. Switch outlet.                                                                                                             |                                                                                     |                                                                                                                                                             |
|  | S3 3-way Switch outlet.                                                                                                            |                                                                                     |                                                                                                                                                             |

## STANDARD CROSS-HATCHING



CAST IRON



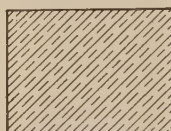
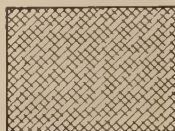
WROUGHT IRON



CAST STEEL



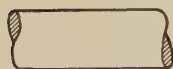
WROUGHT STEEL

BABBITT OR  
WHITE METALCOPPER, BRASS  
OR COMPOSITION

ALUMINUM

RUBBER, VULCANITE  
OR INSULATION

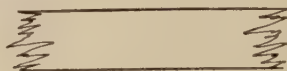
## MISCELLANEOUS SYMBOLS



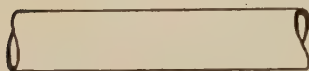
ROUND BAR



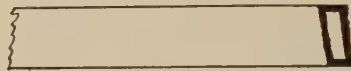
SQUARE BAR



SQUARE (WOOD)



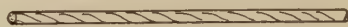
PIPE OR HOLLOW CYLINDER



HOLLOW SQUARE "SECTION"



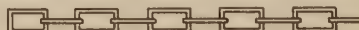
ROPE OR CABLE (Small Scale)



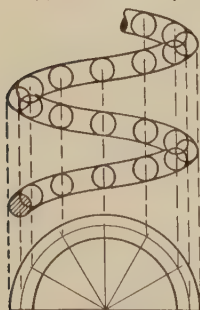
ROPE OR CABLE (Large Scale)



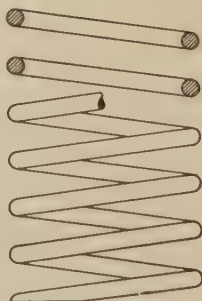
CHAIN (Small Scale)



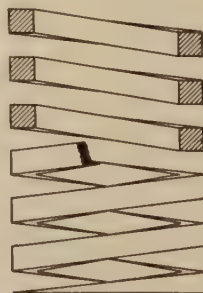
ORNAMENTAL CHAIN (Large Scale)



THEORETICAL PROJECTION



CONVENTIONAL



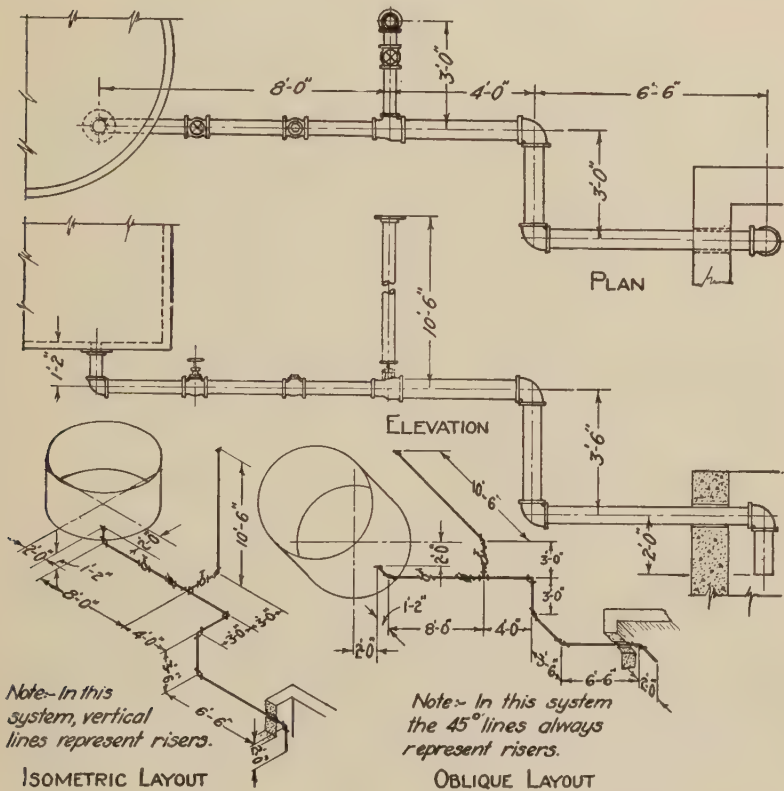
SPRINGS.

**PIPE FITTINGS AND SYMBOLS.** — Lengths of pipe are joined together in one of two ways: by the use of pipe fittings or by the use of the leaded joint. In the first case, the smaller sizes of pipe are usually joined together by standard threaded couplings such as the tee, the elbow, and the union. On the larger

sizes, flanged fittings are used, which may be screwed fittings or shrunk and peened fittings. The flanges are pulled together by bolts and the joint made tight by means of a gasket between the flanges. In the second case, the leaded joints are generally based on the well known principle of the bell and spigot joint although special additional castings are sometimes used.

The figures following show the method of representing some of the common fittings on large-scale drawings. Small-scale drawings show pipe layouts in

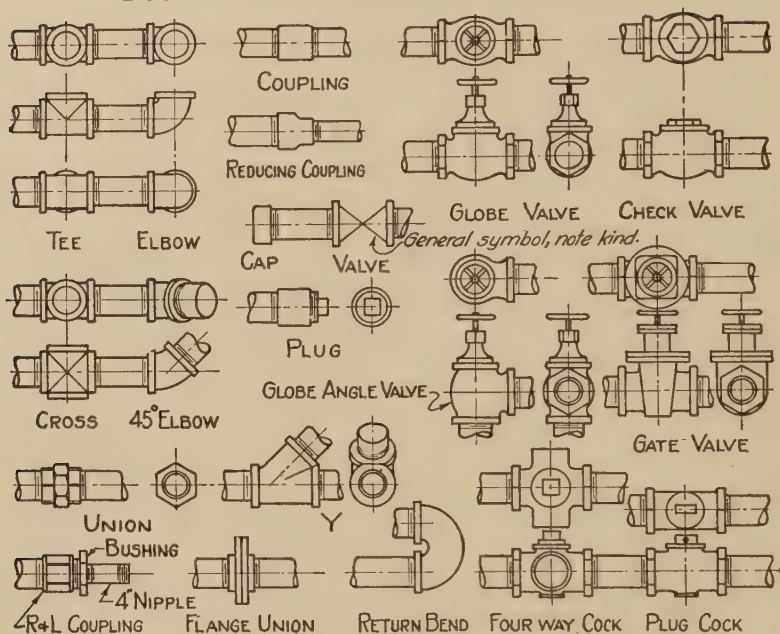
### PIPE LAYOUTS



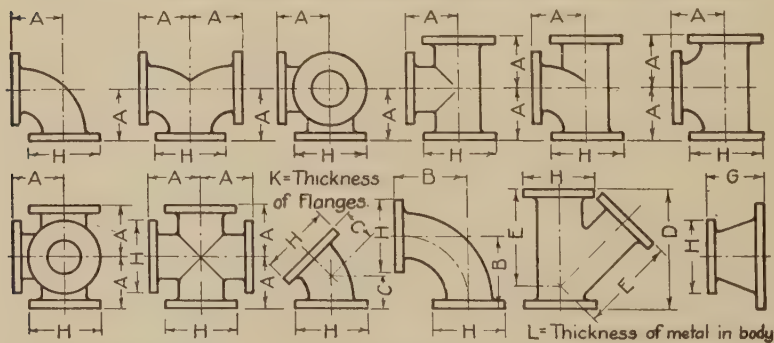
diagrammatic form, as shown in the chart of symbols. Pipe layouts are also made in isometric projection, as illustrated.

Dimensions and notes should be explicit and full. Distances between centers of fittings and centers of pipe lines are necessary. Allowances for "take up" are to be made by the pipe fitter. Pipe under 12 inches in diameter is specified by its nominal inside diameter. Pipe over 12 inches in diameter is called O. D. pipe and is designated by its outside diameter.

## DOUBLE LINE PIPE AND VALVE SYMBOLS



## STANDARD FLANGED FITTINGS, STRAIGHT SIZES — AMERICAN STANDARD

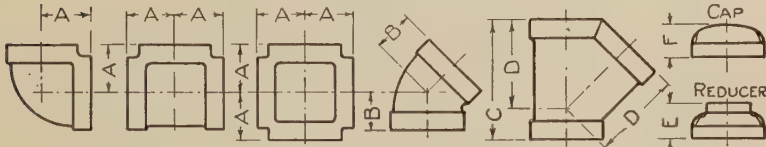


| Size            | A               | B               | C               | D                | E                | G               | H               | K               | L              |
|-----------------|-----------------|-----------------|-----------------|------------------|------------------|-----------------|-----------------|-----------------|----------------|
| 1               | 3 $\frac{1}{4}$ | 5               | 1 $\frac{3}{4}$ | 7 $\frac{1}{2}$  | 5 $\frac{3}{4}$  | ...             | 4               | $\frac{7}{16}$  | $\frac{7}{16}$ |
| 1 $\frac{1}{4}$ | 3 $\frac{3}{4}$ | 5 $\frac{1}{2}$ | 2               | 8                | 6 $\frac{1}{4}$  | ...             | 4 $\frac{1}{2}$ | $\frac{9}{16}$  | $\frac{7}{16}$ |
| 1 $\frac{1}{2}$ | 4               | 6               | 2 $\frac{1}{4}$ | 9                | 7                | ...             | 5               | $\frac{9}{16}$  | $\frac{7}{16}$ |
| 2               | 4 $\frac{1}{2}$ | 6 $\frac{1}{2}$ | 2 $\frac{3}{4}$ | 10 $\frac{1}{2}$ | 8                | ...             | 6               | $\frac{11}{16}$ | $\frac{7}{16}$ |
| 2 $\frac{1}{2}$ | 5               | 7               | 3               | 12               | 9 $\frac{1}{2}$  | ...             | 7               | $\frac{11}{16}$ | $\frac{7}{16}$ |
| 3               | 5 $\frac{1}{2}$ | 7 $\frac{3}{4}$ | 3               | 13               | 10               | 6               | 7 $\frac{1}{2}$ | $\frac{13}{16}$ | $\frac{7}{16}$ |
| 3 $\frac{1}{2}$ | 6               | 8 $\frac{1}{2}$ | 3 $\frac{1}{2}$ | 14 $\frac{1}{2}$ | 11 $\frac{1}{2}$ | 6 $\frac{1}{2}$ | 8 $\frac{1}{2}$ | $\frac{13}{16}$ | $\frac{7}{16}$ |

STANDARD FLANGED FITTINGS, STRAIGHT SIZES — AMER. STD. *Cont.*

| Size            | A                | B                | C               | D                | E                | G                | H                | K                 | L                |
|-----------------|------------------|------------------|-----------------|------------------|------------------|------------------|------------------|-------------------|------------------|
| 4               | 6 $\frac{1}{2}$  | 9                | 4               | 15               | 12               | 7                | 9                | 1 $\frac{5}{16}$  | 1 $\frac{1}{2}$  |
| 4 $\frac{1}{2}$ | 7                | 9 $\frac{1}{2}$  | 4               | 15 $\frac{1}{2}$ | 12 $\frac{1}{2}$ | 7 $\frac{1}{2}$  | 9 $\frac{1}{4}$  | 1 $\frac{5}{16}$  | 1 $\frac{1}{2}$  |
| 5               | 7 $\frac{1}{2}$  | 10 $\frac{1}{4}$ | 4 $\frac{1}{2}$ | 17               | 13 $\frac{1}{2}$ | 8                | 10               | 1 $\frac{5}{16}$  | 1 $\frac{1}{2}$  |
| 6               | 8                | 11 $\frac{1}{2}$ | 5               | 18               | 14 $\frac{1}{2}$ | 9                | 11               | 1 $\frac{5}{16}$  | 1 $\frac{1}{2}$  |
| 7               | 8 $\frac{1}{2}$  | 12 $\frac{1}{2}$ | 5 $\frac{1}{2}$ | 20 $\frac{1}{2}$ | 16 $\frac{1}{2}$ | 10               | 12 $\frac{1}{2}$ | 1 $\frac{1}{16}$  | 1 $\frac{1}{2}$  |
| 8               | 9                | 14               | 5 $\frac{1}{2}$ | 22               | 17 $\frac{1}{2}$ | 11               | 13 $\frac{1}{2}$ | 1 $\frac{1}{8}$   | 1 $\frac{1}{2}$  |
| 9               | 10               | 15 $\frac{1}{4}$ | 6               | 24               | 19 $\frac{1}{2}$ | 11 $\frac{1}{2}$ | 15               | 1 $\frac{1}{8}$   | 1 $\frac{1}{2}$  |
| 10              | 11               | 16 $\frac{1}{2}$ | 6 $\frac{1}{2}$ | 25 $\frac{1}{2}$ | 20 $\frac{1}{2}$ | 12               | 16               | 1 $\frac{1}{8}$   | 1 $\frac{1}{2}$  |
| 12              | 12               | 19               | 7 $\frac{1}{2}$ | 30               | 24 $\frac{1}{2}$ | 14               | 19               | 1 $\frac{1}{4}$   | 1 $\frac{3}{4}$  |
| 14              | 14               | 21 $\frac{1}{2}$ | 7 $\frac{1}{2}$ | 33               | 27               | 16               | 21               | 1 $\frac{3}{8}$   | 1 $\frac{3}{4}$  |
| 15              | 14 $\frac{1}{2}$ | 22 $\frac{3}{4}$ | 8               | 34 $\frac{1}{2}$ | 28 $\frac{1}{2}$ | 17               | 22 $\frac{1}{4}$ | 1 $\frac{3}{8}$   | 1 $\frac{3}{4}$  |
| 16              | 15               | 24               | 8               | 36 $\frac{1}{2}$ | 30               | 18               | 23 $\frac{1}{2}$ | 1 $\frac{7}{16}$  | 1                |
| 18              | 16 $\frac{1}{2}$ | 26 $\frac{1}{2}$ | 8 $\frac{1}{2}$ | 39               | 32               | 19               | 25               | 1 $\frac{9}{16}$  | 1 $\frac{1}{16}$ |
| 20              | 18               | 29               | 9 $\frac{1}{2}$ | 43               | 35               | 20               | 27 $\frac{1}{2}$ | 1 $\frac{11}{16}$ | 1 $\frac{1}{8}$  |
| 22              | 20               | 31 $\frac{1}{2}$ | 10              | 46               | 37 $\frac{1}{2}$ | 22               | 29 $\frac{1}{2}$ | 1 $\frac{3}{8}$   | 1 $\frac{3}{16}$ |
| 24              | 22               | 34               | 11              | 49 $\frac{1}{2}$ | 40 $\frac{1}{2}$ | 24               | 32               | 1 $\frac{5}{8}$   | 1 $\frac{1}{4}$  |

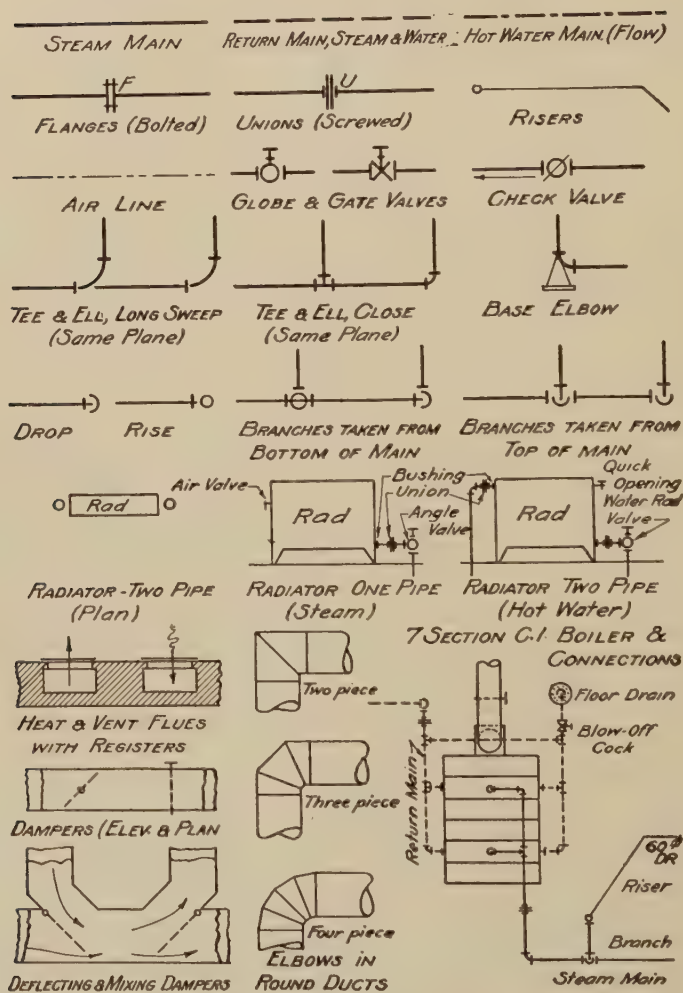
## STANDARD CAST IRON SCREW FITTINGS



| Size<br>Inches  | Dimensions in Inches |                 |       |       |       |       |
|-----------------|----------------------|-----------------|-------|-------|-------|-------|
|                 | A                    | B               | C     | D     | E     | F     |
| 1 $\frac{1}{4}$ | 1 $\frac{3}{16}$     | 3 $\frac{4}{8}$ | ..... | ..... | ..... | ..... |
| 1 $\frac{1}{2}$ | 1 $\frac{5}{16}$     | 3 $\frac{1}{2}$ | ..... | ..... | ..... | ..... |
| 1 $\frac{3}{4}$ | 1 $\frac{7}{8}$      | 3 $\frac{1}{2}$ | ..... | ..... | ..... | ..... |
| 1               | 1 $\frac{1}{2}$      | 3 $\frac{1}{2}$ | ..... | ..... | ..... | ..... |
| 1 $\frac{1}{4}$ | 1 $\frac{3}{8}$      | 3 $\frac{1}{2}$ | ..... | ..... | ..... | ..... |
| 1 $\frac{1}{2}$ | 1 $\frac{5}{8}$      | 3 $\frac{1}{2}$ | ..... | ..... | ..... | ..... |
| 2               | 2 $\frac{1}{4}$      | 3 $\frac{1}{2}$ | ..... | ..... | ..... | ..... |
| 2 $\frac{1}{2}$ | 2 $\frac{1}{2}$      | 3 $\frac{1}{2}$ | ..... | ..... | ..... | ..... |
| 3               | 3 $\frac{1}{8}$      | 3 $\frac{1}{2}$ | ..... | ..... | ..... | ..... |
| 3 $\frac{1}{2}$ | 3 $\frac{1}{4}$      | 3 $\frac{1}{2}$ | ..... | ..... | ..... | ..... |
| 4               | 3 $\frac{1}{2}$      | 3 $\frac{1}{2}$ | ..... | ..... | ..... | ..... |
| 4 $\frac{1}{2}$ | 4 $\frac{1}{8}$      | 3 $\frac{1}{2}$ | ..... | ..... | ..... | ..... |
| 5               | 4 $\frac{1}{4}$      | 3 $\frac{1}{2}$ | ..... | ..... | ..... | ..... |
| 6               | 5 $\frac{1}{8}$      | 3 $\frac{1}{2}$ | ..... | ..... | ..... | ..... |
| 7               | 5 $\frac{1}{4}$      | 3 $\frac{1}{2}$ | ..... | ..... | ..... | ..... |
| 8               | 6 $\frac{1}{8}$      | 3 $\frac{1}{2}$ | ..... | ..... | ..... | ..... |
| 9               | 7 $\frac{1}{8}$      | 3 $\frac{1}{2}$ | ..... | ..... | ..... | ..... |
| 10              | 8 $\frac{1}{8}$      | 3 $\frac{1}{2}$ | ..... | ..... | ..... | ..... |
| 12              | 9 $\frac{1}{2}$      | 3 $\frac{1}{2}$ | ..... | ..... | ..... | ..... |



## HEATING AND VENTILATING SYMBOLS



DIMENSIONS AND WEIGHT OF STANDARD PIPE  
(National Tube Co.)

| Nominal<br>size | Diameters |          | Thickness | Weight per foot, pounds |                             | Threads<br>per inch |
|-----------------|-----------|----------|-----------|-------------------------|-----------------------------|---------------------|
|                 | External  | Internal |           | Plain<br>ends           | Threads<br>and<br>couplings |                     |
| $\frac{1}{8}$   | 0.405     | 0.269    | 0.068     | 0.244                   | 0.245                       | 27                  |
| $\frac{1}{4}$   | 0.540     | 0.364    | 0.088     | 0.424                   | 0.425                       | 18                  |
| $\frac{3}{8}$   | 0.675     | 0.493    | 0.091     | 0.567                   | 0.568                       | 18                  |
| $\frac{1}{2}$   | 0.840     | 0.622    | 0.109     | 0.850                   | 0.852                       | 14                  |
| $\frac{3}{4}$   | 1.050     | 0.824    | 0.113     | 1.130                   | 1.134                       | 14                  |
| 1               | 1.315     | 1.049    | 0.133     | 1.678                   | 1.684                       | 11 $\frac{1}{2}$    |
| 1 $\frac{1}{4}$ | 1.660     | 1.380    | 0.140     | 2.272                   | 2.281                       | 11 $\frac{1}{2}$    |
| 1 $\frac{1}{2}$ | 1.900     | 1.610    | 0.145     | 2.717                   | 2.731                       | 11 $\frac{1}{2}$    |
| 2               | 2.375     | 2.067    | 0.154     | 3.652                   | 3.678                       | 11 $\frac{1}{2}$    |
| 2 $\frac{1}{2}$ | 2.875     | 2.469    | 0.203     | 5.793                   | 5.819                       | 8                   |
| 3               | 3.500     | 3.068    | 0.216     | 7.575                   | 7.616                       | 8                   |
| 3 $\frac{1}{2}$ | 4.000     | 3.548    | 0.226     | 9.109                   | 9.202                       | 8                   |
| 4               | 4.500     | 4.026    | 0.237     | 10.790                  | 10.889                      | 8                   |
| 4 $\frac{1}{2}$ | 5.000     | 4.506    | 0.247     | 12.538                  | 12.642                      | 8                   |
| 5               | 5.563     | 5.047    | 0.258     | 14.617                  | 14.810                      | 8                   |
| 6               | 6.625     | 6.065    | 0.280     | 18.974                  | 19.185                      | 8                   |
| 7               | 7.625     | 7.023    | 0.301     | 23.544                  | 23.769                      | 8                   |
| 8               | 8.625     | 8.071    | 0.277     | 24.696                  | 25.000                      | 8                   |
| 8               | 8.625     | 7.981    | 0.322     | 28.554                  | 28.809                      | 8                   |
| 9               | 9.625     | 8.941    | 0.342     | 33.907                  | 34.188                      | 8                   |
| 10              | 10.750    | 10.192   | 0.279     | 31.201                  | 32.000                      | 8                   |
| 10              | 10.750    | 10.136   | 0.307     | 34.240                  | 35.000                      | 8                   |
| 10              | 10.750    | 10.020   | 0.365     | 40.483                  | 41.132                      | 8                   |
| 11              | 11.750    | 11.000   | 0.375     | 45.557                  | 46.247                      | 8                   |
| 12              | 12.750    | 12.090   | 0.330     | 43.773                  | 45.000                      | 8                   |
| 12              | 12.750    | 12.000   | 0.375     | 49.562                  | 50.706                      | 8                   |

## SHARP V-THREADS — DIAMETERS AND THREADS PER INCH

| Diameter        | Thds. per inch | Diameter at root of thread | Diameter         | Thds. per inch | Diameter at root of thread | Diameter       | Thds. per inch | Diameter at root of thread |
|-----------------|----------------|----------------------------|------------------|----------------|----------------------------|----------------|----------------|----------------------------|
| $\frac{1}{16}$  | 72             | 0.0384                     | $1\frac{1}{8}$   | 7              | 0.8776                     | $2\frac{3}{4}$ | 4              | 2.3170                     |
| $\frac{3}{32}$  | 56             | 0.0628                     | $1\frac{3}{16}$  | 7              | 0.9401                     | $2\frac{7}{8}$ | 4              | 2.4420                     |
| $\frac{1}{8}$   | 40             | 0.0817                     | $1\frac{1}{4}$   | 7              | 1.0026                     | 3              | $3\frac{1}{2}$ | 2.5051                     |
| $\frac{5}{32}$  | 32             | 0.1021                     | $1\frac{5}{16}$  | 7              | 1.0651                     | $3\frac{1}{8}$ | $3\frac{1}{2}$ | 2.6301                     |
| $\frac{3}{16}$  | 24             | 0.1153                     | $1\frac{3}{8}$   | 6              | 1.0863                     | $3\frac{1}{2}$ | $3\frac{1}{2}$ | 2.7551                     |
| $\frac{7}{32}$  | 24             | 0.1465                     | $1\frac{7}{16}$  | 6              | 1.1488                     | $3\frac{3}{8}$ | $3\frac{1}{4}$ | 2.8421                     |
| $\frac{1}{4}$   | 20             | 0.1634                     | $1\frac{1}{2}$   | 6              | 1.2113                     | $3\frac{1}{2}$ | $3\frac{1}{4}$ | 2.9671                     |
| $\frac{5}{16}$  | 18             | 0.2163                     | $1\frac{9}{16}$  | 6              | 1.2738                     | $3\frac{5}{8}$ | $3\frac{1}{4}$ | 3.0921                     |
| $\frac{3}{8}$   | 16             | 0.2667                     | $1\frac{5}{8}$   | 5              | 1.2786                     | $3\frac{3}{4}$ | 3              | 3.1726                     |
| $\frac{7}{16}$  | 14             | 0.3138                     | $1\frac{11}{16}$ | 5              | 1.3411                     | $3\frac{7}{8}$ | 3              | 3.2976                     |
| $\frac{1}{2}$   | 12             | 0.3557                     | $1\frac{3}{4}$   | 5              | 1.4036                     | 4              | 3              | 3.4226                     |
| $\frac{9}{16}$  | 12             | 0.4182                     | $1\frac{7}{8}$   | 5              | 1.4661                     | $4\frac{1}{4}$ | $2\frac{7}{8}$ | 3.6475                     |
| $\frac{5}{8}$   | 11             | 0.4675                     | $1\frac{1}{2}$   | $4\frac{1}{2}$ | 1.4901                     | $4\frac{1}{2}$ | $2\frac{3}{4}$ | 3.8702                     |
| $\frac{11}{16}$ | 11             | 0.5300                     | $1\frac{5}{8}$   | $4\frac{1}{2}$ | 1.5526                     | $4\frac{3}{4}$ | $2\frac{5}{8}$ | 4.0902                     |
| $\frac{3}{4}$   | 10             | 0.5768                     | 2                | $4\frac{3}{4}$ | 1.6151                     | 5              | $2\frac{1}{2}$ | 4.3072                     |
| $\frac{13}{16}$ | 10             | 0.6393                     | $2\frac{1}{8}$   | $4\frac{1}{2}$ | 1.7401                     | $5\frac{1}{2}$ | $2\frac{1}{2}$ | 4.5572                     |
| $\frac{7}{8}$   | 9              | 0.6825                     | $2\frac{1}{4}$   | $4\frac{1}{2}$ | 1.8651                     | $5\frac{3}{4}$ | $2\frac{3}{8}$ | 4.7707                     |
| $\frac{15}{16}$ | 9              | 0.7450                     | $2\frac{3}{8}$   | $4\frac{1}{2}$ | 1.9901                     | $5\frac{1}{4}$ | $2\frac{3}{8}$ | 5.0207                     |
| 1               | 8              | 0.7835                     | $2\frac{1}{2}$   | 4              | 2.0670                     | 6              | $2\frac{1}{4}$ | 5.2302                     |
| $1\frac{1}{16}$ | 8              | 0.8460                     | $2\frac{5}{8}$   | 4              | 2.1920                     | .....          | ...            | .....                      |

## ELEMENTS OF THE SHARP V-THREAD

| Thds. per inch | Depth of thread | Width of flat* | Double depth of thread | Thds. per inch | Depth of thread | Width of flat* | Double depth of thread |
|----------------|-----------------|----------------|------------------------|----------------|-----------------|----------------|------------------------|
| $2\frac{1}{4}$ | 0.3849          | 0.0178         | 0.7698                 | 12             | 0.0722          | 0.0033         | 0.1443                 |
| $2\frac{3}{8}$ | 0.3646          | 0.0168         | 0.7293                 | 13             | 0.0666          | 0.0031         | 0.1332                 |
| $2\frac{1}{2}$ | 0.3464          | 0.0160         | 0.6928                 | 14             | 0.0619          | 0.0029         | 0.1237                 |
| $2\frac{5}{8}$ | 0.3299          | 0.0152         | 0.6598                 | 15             | 0.0577          | 0.0027         | 0.1155                 |
| $2\frac{3}{4}$ | 0.3149          | 0.0145         | 0.6298                 | 16             | 0.0541          | 0.0025         | 0.1083                 |
| $2\frac{7}{8}$ | 0.3012          | 0.0139         | 0.6025                 | 18             | 0.0481          | 0.0022         | 0.0962                 |
| 3              | 0.2887          | 0.0133         | 0.5774                 | 20             | 0.0433          | 0.0020         | 0.0866                 |
| $3\frac{1}{4}$ | 0.2665          | 0.0123         | 0.5329                 | 22             | 0.0394          | 0.0018         | 0.0787                 |
| $3\frac{3}{8}$ | 0.2474          | 0.0114         | 0.4949                 | 24             | 0.0361          | 0.0017         | 0.0722                 |
| 4              | 0.2165          | 0.0100         | 0.4330                 | 26             | 0.0333          | 0.0015         | 0.0666                 |
| $4\frac{1}{8}$ | 0.1925          | 0.0089         | 0.3849                 | 28             | 0.0309          | 0.0014         | 0.0619                 |
| 5              | 0.1732          | 0.0080         | 0.3464                 | 30             | 0.0289          | 0.0013         | 0.0577                 |
| $5\frac{1}{8}$ | 0.1575          | 0.0073         | 0.3149                 | 32             | 0.0271          | 0.0012         | 0.0541                 |
| 6              | 0.1443          | 0.0067         | 0.2887                 | 34             | 0.0255          | 0.0012         | 0.0509                 |
| 7              | 0.1237          | 0.0057         | 0.2474                 | 36             | 0.0241          | 0.0011         | 0.0481                 |
| 8              | 0.1083          | 0.0050         | 0.2165                 | 38             | 0.0228          | 0.0011         | 0.0456                 |
| 9              | 0.0962          | 0.0044         | 0.1925                 | 40             | 0.0217          | 0.0010         | 0.0433                 |
| 10             | 0.0866          | 0.0040         | 0.1732                 | 42             | 0.0206          | 0.0010         | 0.0412                 |
| 11             | 0.0787          | 0.0036         | 0.1575                 | 44             | 0.0197          | 0.0009         | 0.0394                 |

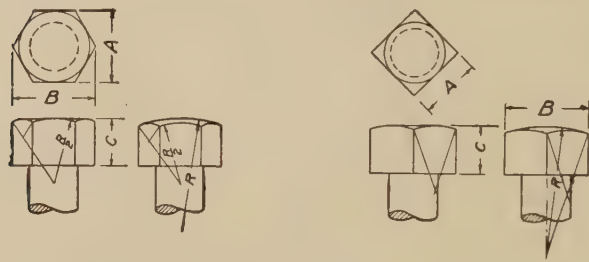
\* Flat for avoiding extreme sharp corner usually equals  $\frac{1}{16}$  of the pitch.

## U. S. STANDARD THREADS, BOLTS AND NUTS

The tap drill diameters in the table provide for a slight clearance at the root of the thread, in order to facilitate tapping and to reduce tap break-ages. If full threads are required, use the diameters at the root of the threads for the tap drill diameters.

| Diam-eter      | No. of threads per inch | Diameter at root of thread | Diam-eter of tap drill | Dimensions of nuts and bolt heads                                                                   |                 |        |        |                 |
|----------------|-------------------------|----------------------------|------------------------|-----------------------------------------------------------------------------------------------------|-----------------|--------|--------|-----------------|
|                |                         |                            |                        | A = thickness of nut<br>B = width across flats<br>C = width across corners<br>D = thickness of head |                 |        |        |                 |
|                |                         |                            |                        | A                                                                                                   | B               | C      |        | D               |
|                |                         |                            |                        |                                                                                                     |                 | Hex.   | Square |                 |
| $\frac{1}{4}$  | 20                      | 0.185                      | $\frac{1}{16}$         | Same as diameter — first column                                                                     | $\frac{1}{2}$   | 0.578  | 0.707  | $\frac{1}{2}$   |
| $\frac{5}{16}$ | 18                      | 0.240                      | $\frac{1}{8}$          |                                                                                                     | $\frac{9}{16}$  | 0.686  | 0.840  | $\frac{9}{16}$  |
| $\frac{3}{8}$  | 16                      | 0.294                      | $\frac{5}{16}$         |                                                                                                     | $\frac{1}{2}$   | 0.794  | 0.972  | $\frac{1}{2}$   |
| $\frac{7}{16}$ | 14                      | 0.345                      | $\frac{3}{8}$          |                                                                                                     | $\frac{11}{16}$ | 0.902  | 1.105  | $\frac{11}{16}$ |
| $\frac{1}{2}$  | 13                      | 0.400                      | $\frac{7}{16}$         |                                                                                                     | $\frac{3}{4}$   | 1.011  | 1.237  | $\frac{3}{4}$   |
| $\frac{9}{16}$ | 12                      | 0.454                      | $\frac{1}{2}$          |                                                                                                     | $\frac{7}{8}$   | 1.119  | 1.370  | $\frac{7}{8}$   |
| $\frac{5}{8}$  | 11                      | 0.507                      | $\frac{9}{16}$         |                                                                                                     | $\frac{1}{2}$   | 1.227  | 1.502  | $\frac{1}{2}$   |
| $\frac{3}{4}$  | 10                      | 0.620                      | $\frac{5}{8}$          |                                                                                                     | $\frac{11}{16}$ | 1.444  | 1.768  | $\frac{11}{16}$ |
| $\frac{7}{8}$  | 9                       | 0.731                      | $\frac{3}{4}$          |                                                                                                     | $\frac{1}{2}$   | 1.660  | 2.033  | $\frac{1}{2}$   |
| 1              | 8                       | 0.838                      | $\frac{7}{8}$          |                                                                                                     | $\frac{1}{2}$   | 1.877  | 2.298  | $\frac{1}{2}$   |
| $\frac{1}{8}$  | 7                       | 0.939                      | $\frac{1}{2}$          |                                                                                                     | $\frac{11}{16}$ | 2.093  | 2.563  | $\frac{11}{16}$ |
| $\frac{1}{4}$  | 7                       | 1.064                      | $\frac{3}{8}$          |                                                                                                     | 2               | 2.310  | 2.828  | 2               |
| $\frac{1}{2}$  | 6                       | 1.158                      | $\frac{1}{2}$          |                                                                                                     | $\frac{3}{16}$  | 2.527  | 3.093  | $\frac{3}{16}$  |
| $\frac{3}{4}$  | 6                       | 1.283                      | $\frac{5}{8}$          |                                                                                                     | $\frac{1}{4}$   | 2.743  | 3.358  | $\frac{1}{4}$   |
| $\frac{1}{2}$  | $5\frac{1}{2}$          | 1.389                      | $\frac{3}{4}$          |                                                                                                     | $\frac{9}{16}$  | 2.960  | 3.623  | $\frac{9}{16}$  |
| $\frac{3}{4}$  | 5                       | 1.490                      | $\frac{7}{8}$          |                                                                                                     | $\frac{1}{2}$   | 3.176  | 3.889  | $\frac{1}{2}$   |
| $\frac{1}{2}$  | 5                       | 1.615                      | $\frac{1}{2}$          |                                                                                                     | $\frac{5}{16}$  | 3.393  | 4.154  | $\frac{5}{16}$  |
| 2              | $4\frac{1}{2}$          | 1.711                      | $\frac{3}{4}$          |                                                                                                     | $\frac{3}{8}$   | 3.609  | 4.419  | $\frac{3}{8}$   |
| $2\frac{1}{8}$ | $4\frac{1}{8}$          | 1.961                      | $\frac{1}{2}$          |                                                                                                     | $\frac{1}{2}$   | 4.043  | 4.949  | $\frac{1}{2}$   |
| $2\frac{1}{4}$ | 4                       | 2.175                      | $\frac{3}{8}$          |                                                                                                     | $\frac{3}{4}$   | 4.476  | 5.479  | $\frac{3}{4}$   |
| $2\frac{3}{4}$ | 4                       | 2.425                      | $\frac{1}{4}$          |                                                                                                     | 4               | 4.909  | 6.010  | 4               |
| 3              | $3\frac{1}{2}$          | 2.629                      | $\frac{1}{8}$          |                                                                                                     | $\frac{1}{2}$   | 5.342  | 6.540  | $\frac{1}{2}$   |
| $3\frac{1}{4}$ | $3\frac{3}{4}$          | 2.879                      | $\frac{1}{16}$         |                                                                                                     | 5               | 5.775  | 7.070  | 5               |
| $3\frac{1}{2}$ | 3                       | 3.100                      | $\frac{1}{8}$          |                                                                                                     | $\frac{3}{4}$   | 6.208  | 7.600  | $\frac{3}{4}$   |
| $3\frac{3}{4}$ | 3                       | 3.317                      | $\frac{1}{16}$         |                                                                                                     | $\frac{1}{2}$   | 6.641  | 8.131  | $\frac{1}{2}$   |
| 4              | 3                       | 3.567                      | $\frac{1}{8}$          |                                                                                                     | $\frac{3}{8}$   | 7.074  | 8.661  | $\frac{3}{8}$   |
| $4\frac{1}{4}$ | $2\frac{7}{8}$          | 3.798                      | $\frac{1}{16}$         |                                                                                                     | $\frac{1}{2}$   | 7.508  | 9.191  | $\frac{1}{2}$   |
| $4\frac{1}{2}$ | $2\frac{3}{4}$          | 4.028                      | $\frac{1}{8}$          |                                                                                                     | $\frac{1}{4}$   | 7.941  | 9.721  | $\frac{1}{4}$   |
| $4\frac{3}{4}$ | $2\frac{1}{2}$          | 4.255                      | $\frac{1}{16}$         |                                                                                                     | $\frac{1}{2}$   | 8.374  | 10.252 | $\frac{1}{2}$   |
| 5              | $2\frac{1}{4}$          | 4.480                      | $\frac{1}{8}$          |                                                                                                     | $\frac{3}{8}$   | 8.807  | 10.782 | $\frac{3}{8}$   |
| $5\frac{1}{4}$ | $2\frac{1}{8}$          | 4.730                      | $\frac{1}{16}$         |                                                                                                     | 8               | 9.240  | 11.312 | 8               |
| $5\frac{1}{2}$ | $2\frac{1}{4}$          | 4.953                      | $\frac{1}{8}$          |                                                                                                     | $\frac{1}{2}$   | 9.673  | 11.842 | $\frac{1}{2}$   |
| $5\frac{3}{4}$ | $2\frac{3}{8}$          | 5.203                      | $\frac{1}{16}$         |                                                                                                     | $\frac{1}{4}$   | 10.106 | 12.373 | $\frac{1}{4}$   |
| 6              | $2\frac{1}{4}$          | 5.423                      | $\frac{1}{8}$          |                                                                                                     | $\frac{1}{2}$   | 10.539 | 12.903 | $\frac{1}{2}$   |

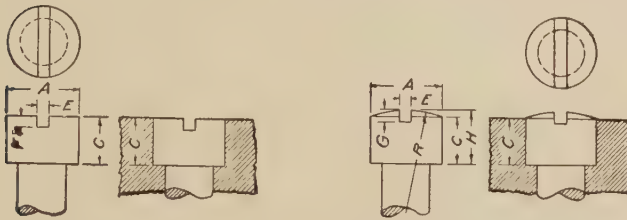
## STANDARD HEXAGONAL AND SQUARE HEAD CAP SCREWS



| Diam-eter                                                                                                                                                                                         | No. of threads per inch                                     | Diam-eter at root of threads                      | Diam-eter of tap drill                            | Dimensions of cap screw heads                                                                                                                                                                       |                                                                                                                                                                                                                   |                                                                                                                                                                                                          |                                                                                                                                                                                                            |                                                                                                                                                                                                   |                                                                                                                                                                                                          |                                                                                                                                                                                                                                  |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------|---------------------------------------------------|---------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                   |                                                             |                                                   |                                                   | A = width across flats<br>B = width across corners<br>C = thickness of head<br>R = radius of head                                                                                                   |                                                                                                                                                                                                                   |                                                                                                                                                                                                          |                                                                                                                                                                                                            |                                                                                                                                                                                                   |                                                                                                                                                                                                          |                                                                                                                                                                                                                                  |
|                                                                                                                                                                                                   |                                                             |                                                   |                                                   | A                                                                                                                                                                                                   |                                                                                                                                                                                                                   | B                                                                                                                                                                                                        |                                                                                                                                                                                                            | C                                                                                                                                                                                                 | R                                                                                                                                                                                                        |                                                                                                                                                                                                                                  |
|                                                                                                                                                                                                   |                                                             |                                                   |                                                   | Hex.                                                                                                                                                                                                | Square                                                                                                                                                                                                            | Hex.                                                                                                                                                                                                     | Square                                                                                                                                                                                                     |                                                                                                                                                                                                   | Hex.                                                                                                                                                                                                     | Square                                                                                                                                                                                                                           |
| $\frac{1}{4}$<br>$\frac{5}{16}$<br>$\frac{3}{8}$<br>$\frac{7}{16}$<br>$\frac{1}{2}$<br>$\frac{9}{16}$<br>$\frac{5}{8}$<br>$\frac{3}{4}$<br>$\frac{7}{8}$<br>1<br>$1\frac{1}{8}$<br>$1\frac{1}{4}$ | 20<br>18<br>16<br>14<br>13<br>12<br>11<br>10<br>9<br>8<br>7 | Same as for U. S. Standard Bolt or Sharp V-Thread | Same as for U. S. Standard Bolt or Sharp V-Thread | $\frac{7}{16}$<br>$\frac{1}{2}$<br>$\frac{1}{2}$<br>$\frac{9}{16}$<br>$\frac{5}{8}$<br>$\frac{3}{4}$<br>$1\frac{1}{8}$<br>$1\frac{1}{4}$<br>$1\frac{1}{2}$<br>1<br>$1\frac{1}{8}$<br>$1\frac{1}{4}$ | $\frac{3}{8}$<br>$\frac{7}{16}$<br>$\frac{1}{2}$<br>$\frac{9}{16}$<br>$\frac{5}{8}$<br>$1\frac{1}{8}$<br>$1\frac{1}{4}$<br>$1\frac{1}{2}$<br>$1\frac{3}{4}$<br>$2\frac{1}{8}$<br>$2\frac{1}{4}$<br>$2\frac{1}{2}$ | $\frac{1}{2}$<br>$\frac{3}{8}$<br>$\frac{3}{8}$<br>$\frac{3}{8}$<br>$\frac{3}{8}$<br>$\frac{3}{8}$<br>$\frac{3}{8}$<br>$\frac{3}{8}$<br>$\frac{3}{8}$<br>$\frac{3}{8}$<br>$\frac{3}{8}$<br>$\frac{3}{8}$ | $\frac{17}{32}$<br>$\frac{1}{2}$<br>$\frac{1}{2}$<br>$\frac{1}{2}$<br>$\frac{1}{2}$<br>$\frac{1}{2}$<br>$\frac{1}{2}$<br>$\frac{1}{2}$<br>$\frac{1}{2}$<br>$\frac{1}{2}$<br>$\frac{1}{2}$<br>$\frac{1}{2}$ | $\frac{1}{4}$<br>$\frac{5}{16}$<br>$\frac{3}{8}$<br>$\frac{7}{16}$<br>$\frac{1}{2}$<br>$\frac{9}{16}$<br>$\frac{5}{8}$<br>$\frac{3}{4}$<br>$\frac{7}{8}$<br>1<br>$1\frac{1}{8}$<br>$1\frac{1}{4}$ | $\frac{3}{4}$<br>$\frac{5}{8}$<br>$\frac{5}{8}$<br>$\frac{5}{8}$<br>$\frac{5}{8}$<br>$\frac{5}{8}$<br>$\frac{5}{8}$<br>$\frac{5}{8}$<br>$\frac{5}{8}$<br>$\frac{5}{8}$<br>$\frac{5}{8}$<br>$\frac{5}{8}$ | $\frac{25}{32}$<br>$\frac{15}{16}$<br>$\frac{15}{16}$<br>$\frac{15}{16}$<br>$\frac{15}{16}$<br>$\frac{15}{16}$<br>$\frac{15}{16}$<br>$\frac{15}{16}$<br>$\frac{15}{16}$<br>$\frac{15}{16}$<br>$\frac{15}{16}$<br>$\frac{15}{16}$ |

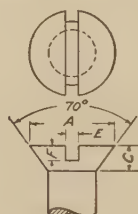
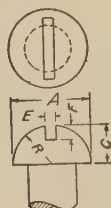


## STANDARD FLAT AND OVAL FILLISTER HEAD CAP SCREWS



| Diameter | No. of threads per inch | Diameter of root of thread                        | Diameter of tap drill                             | Dimensions of cap screw heads |                |                |               |      |                |                 |
|----------|-------------------------|---------------------------------------------------|---------------------------------------------------|-------------------------------|----------------|----------------|---------------|------|----------------|-----------------|
|          |                         |                                                   |                                                   | A                             | C              | H              | R             | E    | F              | G               |
| 1        | 40                      | Same as for U. S. Standard Bolt or Sharp V-thread | Same as for U. S. Standard Bolt or Sharp V-thread | $\frac{3}{16}$                | $\frac{1}{8}$  | $\frac{9}{64}$ | $\frac{1}{4}$ | .032 | $\frac{1}{16}$ | $\frac{5}{64}$  |
|          | 32                      |                                                   |                                                   | $\frac{1}{4}$                 | $\frac{3}{16}$ | $\frac{7}{32}$ | $\frac{1}{2}$ | .040 | $\frac{1}{16}$ | $\frac{3}{32}$  |
|          | 20                      |                                                   |                                                   | $\frac{1}{2}$                 | $\frac{1}{4}$  | $\frac{9}{32}$ | $\frac{3}{4}$ | .064 | $\frac{1}{16}$ | $\frac{3}{32}$  |
|          | 18                      |                                                   |                                                   | $\frac{5}{16}$                | $\frac{5}{16}$ | $\frac{5}{32}$ | $\frac{3}{4}$ | .072 | $\frac{5}{64}$ | $\frac{1}{8}$   |
|          | 16                      |                                                   |                                                   | $\frac{3}{8}$                 | $\frac{3}{8}$  | $\frac{1}{16}$ | $\frac{3}{4}$ | .091 | $\frac{3}{32}$ | $\frac{9}{64}$  |
|          | 14                      |                                                   |                                                   | $\frac{7}{16}$                | $\frac{7}{16}$ | $\frac{1}{2}$  | $\frac{3}{4}$ | .102 | $\frac{7}{64}$ | $\frac{11}{64}$ |
|          | 13                      |                                                   |                                                   | $\frac{1}{2}$                 | $\frac{1}{2}$  | $\frac{9}{16}$ | $\frac{3}{4}$ | .114 | $\frac{1}{8}$  | $\frac{3}{16}$  |
|          | 12                      |                                                   |                                                   | $\frac{9}{16}$                | $\frac{9}{16}$ | $\frac{1}{4}$  | $\frac{3}{4}$ | .114 | $\frac{9}{64}$ | $\frac{7}{16}$  |
|          | 11                      |                                                   |                                                   | $\frac{5}{8}$                 | $\frac{5}{8}$  | $\frac{1}{2}$  | $\frac{3}{4}$ | .128 | $\frac{3}{32}$ | $\frac{15}{64}$ |
|          | 10                      |                                                   |                                                   | $\frac{3}{4}$                 | $\frac{3}{4}$  | $\frac{5}{8}$  | $\frac{3}{4}$ | .133 | $\frac{3}{16}$ | $\frac{9}{32}$  |
|          | 9                       |                                                   |                                                   | $\frac{7}{8}$                 | $\frac{7}{8}$  | $\frac{3}{4}$  | $\frac{3}{4}$ | .133 | $\frac{7}{16}$ | $\frac{5}{16}$  |
|          | 8                       |                                                   |                                                   | 1                             | 1              | $\frac{7}{8}$  | 1             | .165 | $\frac{1}{4}$  | $\frac{3}{8}$   |
|          |                         |                                                   |                                                   | $\frac{1}{4}$                 |                | $\frac{1}{8}$  | $\frac{1}{4}$ |      |                |                 |
|          |                         |                                                   |                                                   | 1                             | 1              | $\frac{1}{2}$  | 1             |      |                |                 |
|          |                         |                                                   |                                                   | $\frac{1}{2}$                 | $\frac{1}{2}$  | $\frac{3}{4}$  | $\frac{1}{2}$ |      |                |                 |
|          |                         |                                                   |                                                   | $\frac{3}{4}$                 | $\frac{3}{4}$  | $\frac{5}{8}$  | $\frac{3}{4}$ |      |                |                 |

## STANDARD BUTTON AND FLAT COUNTERSUNK HEAD CAP SCREWS



| Dimensions of cap screw heads                                                                                 |                       |                            |                       |        |        |        |      |      |        |       |   |
|---------------------------------------------------------------------------------------------------------------|-----------------------|----------------------------|-----------------------|--------|--------|--------|------|------|--------|-------|---|
| A = diameter of head<br>C = thickness of head<br>R = radius of head<br>E = width of slot<br>F = depth of slot |                       |                            |                       |        |        |        |      |      |        |       |   |
| Diameter                                                                                                      | No. of thds. per inch | Diameter of root of thread | Diameter of tap drill |        |        |        |      |      |        |       |   |
|                                                                                                               |                       |                            |                       | A      |        | C      |      | R    | E      |       | F |
| Button                                                                                                        | Flat                  | Button                     | Flat                  | Button | Flat   | Button | Flat |      | Button | Flat  |   |
| 1/4                                                                                                           | 40                    | 7/32                       | 1/4                   | 7/32   | 3/32   | 7/64   | .035 | .040 | 3/64   | 3/64  |   |
| 5/16                                                                                                          | 32                    | 9/32                       | 1/4                   | 9/32   | 3/16   | 3/8    | .051 | .064 | 1/16   | 1/16  |   |
| 3/8                                                                                                           | 20                    | 7/16                       | 5/16                  | 7/16   | 7/16   | 1/2    | .072 | .072 | 5/64   | 5/64  |   |
| 1/2                                                                                                           | 18                    | 9/16                       | 3/8                   | 9/16   | 3/8    | 3/4    | .091 | .102 | 3/32   | 3/32  |   |
| 5/8                                                                                                           | 16                    | 5/8                        | 1/2                   | 5/8    | 1/2    | 7/8    | .102 | .114 | 7/64   | 7/64  |   |
| 3/4                                                                                                           | 14                    | 3/4                        | 3/4                   | 3/4    | 3/4    | 1      | .114 | .114 | 1/8    | 1/8   |   |
| 7/8                                                                                                           | 13                    | 13/16                      | 13/16                 | 13/16  | 13/16  | 1 1/8  | .114 | .128 | 5/32   | 5/32  |   |
| 1                                                                                                             | 12                    | 1 1/16                     | 1                     | 1 1/16 | 1 1/16 | 1 1/4  | .114 | .133 | 11/64  | 11/64 |   |
| 1 1/8                                                                                                         | 11                    | 1 1/8                      | 1 1/8                 | 1 1/8  | 1 1/8  | 1 3/8  | .133 | .133 | 3/16   | 3/16  |   |
| 1 1/4                                                                                                         | 10                    | 1 1/4                      | 1 1/4                 | 1 1/4  | 1 1/4  | 1 1/2  | .133 | .133 | 7/32   | 7/32  |   |
| Same as for U. S. Standard Bolt or Sharp V-Thread                                                             |                       |                            |                       |        |        |        |      |      |        |       |   |
| Same as for U. S. Standard Bolt or Sharp V-Thread                                                             |                       |                            |                       |        |        |        |      |      |        |       |   |

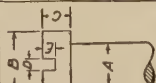
## A. S. M. E. STANDARD MACHINE SCREWS

| Num-<br>ber | Out-<br>side<br>diam-<br>eter | Thds.<br>per<br>inch | Flat head screws                                                                                                                                                                                                             |       |       |       | Oval fillister head screws                                                                                                                                                                                                             |        |       |       |        |
|-------------|-------------------------------|----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|-------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|-------|-------|--------|
|             |                               |                      | B                                                                                                                                                                                                                            | C     | D     | E     | B                                                                                                                                                                                                                                      | C      | D     | E     | F      |
|             |                               |                      | <p>A = diameter of body<br/>B = 2A - 0.008 = diameter of head<br/>C = <math>\frac{A - 0.008}{1.739}</math> = thickness of head<br/>D = 0.173A + 0.015 = width of slot<br/>E = <math>\frac{1}{2}</math> C = depth of slot</p> |       |       |       | <p>A = diameter of body<br/>B = 1.04A - 0.009 = dia. of head<br/>C = 0.66A - 0.002 = height of side<br/>D = 0.173A + 0.015 = width of slot<br/>E = <math>\frac{1}{2}</math> F = depth of slot<br/>F = 0.134 B + C = height of head</p> |        |       |       |        |
| 0           | 0.060                         | 80                   | 0.112                                                                                                                                                                                                                        | 0.029 | 0.025 | 0.010 | 0.0894                                                                                                                                                                                                                                 | 0.0376 | 0.025 | 0.025 | 0.0496 |
| 1           | 0.073                         | 72                   | 0.138                                                                                                                                                                                                                        | 0.037 | 0.028 | 0.012 | 0.1107                                                                                                                                                                                                                                 | 0.0461 | 0.028 | 0.030 | 0.0609 |
| 2           | 0.086                         | 64                   | 0.164                                                                                                                                                                                                                        | 0.045 | 0.030 | 0.015 | 0.1320                                                                                                                                                                                                                                 | 0.0548 | 0.030 | 0.036 | 0.0725 |
| 3           | 0.099                         | 56                   | 0.190                                                                                                                                                                                                                        | 0.052 | 0.032 | 0.017 | 0.1530                                                                                                                                                                                                                                 | 0.0633 | 0.032 | 0.042 | 0.0838 |
| 4           | 0.112                         | 48                   | 0.216                                                                                                                                                                                                                        | 0.060 | 0.034 | 0.020 | 0.1747                                                                                                                                                                                                                                 | 0.0719 | 0.034 | 0.048 | 0.0953 |
| 5           | 0.125                         | 44                   | 0.242                                                                                                                                                                                                                        | 0.067 | 0.037 | 0.022 | 0.1960                                                                                                                                                                                                                                 | 0.0805 | 0.037 | 0.053 | 0.1068 |
| 6           | 0.138                         | 40                   | 0.262                                                                                                                                                                                                                        | 0.075 | 0.039 | 0.025 | 0.2170                                                                                                                                                                                                                                 | 0.0890 | 0.039 | 0.059 | 0.1180 |
| 7           | 0.151                         | 36                   | 0.294                                                                                                                                                                                                                        | 0.082 | 0.041 | 0.027 | 0.2386                                                                                                                                                                                                                                 | 0.0976 | 0.041 | 0.065 | 0.1296 |
| 8           | 0.164                         | 36                   | 0.320                                                                                                                                                                                                                        | 0.090 | 0.043 | 0.030 | 0.2599                                                                                                                                                                                                                                 | 0.1062 | 0.043 | 0.071 | 0.1410 |
| 9           | 0.177                         | 32                   | 0.346                                                                                                                                                                                                                        | 0.097 | 0.046 | 0.032 | 0.2813                                                                                                                                                                                                                                 | 0.1148 | 0.046 | 0.076 | 0.1524 |
| 10          | 0.190                         | 30                   | 0.372                                                                                                                                                                                                                        | 0.105 | 0.048 | 0.035 | 0.3026                                                                                                                                                                                                                                 | 0.1234 | 0.048 | 0.082 | 0.1639 |
| 12          | 0.216                         | 28                   | 0.424                                                                                                                                                                                                                        | 0.120 | 0.052 | 0.040 | 0.3452                                                                                                                                                                                                                                 | 0.1405 | 0.052 | 0.093 | 0.1868 |
| 14          | 0.242                         | 24                   | 0.472                                                                                                                                                                                                                        | 0.135 | 0.057 | 0.045 | 0.3879                                                                                                                                                                                                                                 | 0.1577 | 0.057 | 0.105 | 0.2097 |
| 16          | 0.268                         | 22                   | 0.528                                                                                                                                                                                                                        | 0.150 | 0.061 | 0.050 | 0.4305                                                                                                                                                                                                                                 | 0.1748 | 0.061 | 0.116 | 0.2325 |
| 18          | 0.294                         | 20                   | 0.580                                                                                                                                                                                                                        | 0.164 | 0.066 | 0.055 | 0.4731                                                                                                                                                                                                                                 | 0.1920 | 0.066 | 0.128 | 0.2554 |
| 20          | 0.320                         | 20                   | 0.632                                                                                                                                                                                                                        | 0.179 | 0.070 | 0.060 | 0.5158                                                                                                                                                                                                                                 | 0.2092 | 0.070 | 0.140 | 0.2783 |
| 22          | 0.346                         | 18                   | 0.682                                                                                                                                                                                                                        | 0.194 | 0.075 | 0.065 | 0.5584                                                                                                                                                                                                                                 | 0.2263 | 0.075 | 0.150 | 0.3011 |
| 24          | 0.372                         | 16                   | 0.732                                                                                                                                                                                                                        | 0.209 | 0.079 | 0.070 | 0.6010                                                                                                                                                                                                                                 | 0.2435 | 0.079 | 0.162 | 0.3240 |
| 26          | 0.398                         | 16                   | 0.788                                                                                                                                                                                                                        | 0.224 | 0.084 | 0.075 | 0.6437                                                                                                                                                                                                                                 | 0.2606 | 0.084 | 0.173 | 0.3469 |
| 28          | 0.424                         | 14                   | 0.840                                                                                                                                                                                                                        | 0.239 | 0.088 | 0.080 | 0.6863                                                                                                                                                                                                                                 | 0.2778 | 0.088 | 0.185 | 0.3698 |
| 30          | 0.450                         | 14                   | 0.892                                                                                                                                                                                                                        | 0.254 | 0.093 | 0.085 | 0.7270                                                                                                                                                                                                                                 | 0.2950 | 0.093 | 0.201 | 0.4024 |

## A.S.M.E. STANDARD MACHINE SCREWS

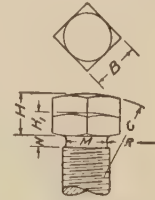
| Number | Outside diameter | Threads per inch | Flat fullister head screws |   |   |   |  | Round head screws |   |   |   |  |
|--------|------------------|------------------|----------------------------|---|---|---|--|-------------------|---|---|---|--|
|        |                  |                  | B                          | C | D | E |  | B                 | C | D | E |  |

|    |       |    |                                                                                                                                                                                 |        |       |       |  |                                                                                                                                                                                                                                                                    |       |       |       |  |
|----|-------|----|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|-------|-------|--|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|-------|-------|--|
|    |       |    | A = diameter of body<br>B = 1.64A - 0.009 = diameter of head<br>C = 0.86A - 0.002 = height of head<br>D = 0.173A + 0.015 = width of slot<br>E = $\frac{1}{2}$ C = depth of slot |        |       |       |  | <br>A = diameter of body<br>B = 1.85A - 0.005 = diameter of head<br>C = 0.7A = height of head<br>D = 0.173A + 0.015 = width of slot<br>E = $\frac{1}{2}$ C + 0.01 = depth of slot |       |       |       |  |
| 0  | 0.060 | 80 | 0.0894                                                                                                                                                                          | 0.0376 | 0.025 | 0.019 |  | 0.106                                                                                                                                                                                                                                                              | 0.042 | 0.025 | 0.031 |  |
| 1  | 0.073 | 72 | 0.1107                                                                                                                                                                          | 0.0461 | 0.028 | 0.023 |  | 0.130                                                                                                                                                                                                                                                              | 0.051 | 0.028 | 0.035 |  |
| 2  | 0.086 | 64 | 0.1320                                                                                                                                                                          | 0.0548 | 0.030 | 0.027 |  | 0.154                                                                                                                                                                                                                                                              | 0.060 | 0.030 | 0.040 |  |
| 3  | 0.099 | 56 | 0.1530                                                                                                                                                                          | 0.0633 | 0.032 | 0.032 |  | 0.178                                                                                                                                                                                                                                                              | 0.069 | 0.032 | 0.044 |  |
| 4  | 0.112 | 48 | 0.1747                                                                                                                                                                          | 0.0719 | 0.034 | 0.036 |  | 0.202                                                                                                                                                                                                                                                              | 0.078 | 0.034 | 0.049 |  |
| 5  | 0.125 | 44 | 0.1960                                                                                                                                                                          | 0.0805 | 0.037 | 0.040 |  | 0.226                                                                                                                                                                                                                                                              | 0.087 | 0.037 | 0.053 |  |
| 6  | 0.138 | 40 | 0.2170                                                                                                                                                                          | 0.0890 | 0.039 | 0.044 |  | 0.250                                                                                                                                                                                                                                                              | 0.096 | 0.039 | 0.058 |  |
| 7  | 0.151 | 36 | 0.2386                                                                                                                                                                          | 0.0976 | 0.041 | 0.049 |  | 0.274                                                                                                                                                                                                                                                              | 0.105 | 0.041 | 0.062 |  |
| 8  | 0.164 | 36 | 0.2599                                                                                                                                                                          | 0.1062 | 0.043 | 0.053 |  | 0.298                                                                                                                                                                                                                                                              | 0.114 | 0.043 | 0.067 |  |
| 9  | 0.177 | 32 | 0.2813                                                                                                                                                                          | 0.1148 | 0.046 | 0.057 |  | 0.322                                                                                                                                                                                                                                                              | 0.123 | 0.046 | 0.071 |  |
| 10 | 0.190 | 30 | 0.3026                                                                                                                                                                          | 0.1234 | 0.048 | 0.062 |  | 0.346                                                                                                                                                                                                                                                              | 0.133 | 0.048 | 0.076 |  |
| 12 | 0.216 | 28 | 0.3452                                                                                                                                                                          | 0.1405 | 0.052 | 0.070 |  | 0.394                                                                                                                                                                                                                                                              | 0.151 | 0.052 | 0.085 |  |
| 14 | 0.242 | 24 | 0.3879                                                                                                                                                                          | 0.1577 | 0.057 | 0.079 |  | 0.443                                                                                                                                                                                                                                                              | 0.169 | 0.057 | 0.094 |  |
| 16 | 0.268 | 22 | 0.4305                                                                                                                                                                          | 0.1748 | 0.061 | 0.087 |  | 0.491                                                                                                                                                                                                                                                              | 0.187 | 0.061 | 0.103 |  |
| 18 | 0.294 | 20 | 0.4731                                                                                                                                                                          | 0.1920 | 0.066 | 0.096 |  | 0.539                                                                                                                                                                                                                                                              | 0.205 | 0.066 | 0.112 |  |
| 20 | 0.320 | 18 | 0.5158                                                                                                                                                                          | 0.2092 | 0.070 | 0.104 |  | 0.587                                                                                                                                                                                                                                                              | 0.224 | 0.070 | 0.122 |  |
| 22 | 0.346 | 18 | 0.5584                                                                                                                                                                          | 0.2263 | 0.075 | 0.113 |  | 0.635                                                                                                                                                                                                                                                              | 0.242 | 0.075 | 0.131 |  |
| 24 | 0.372 | 16 | 0.6010                                                                                                                                                                          | 0.2435 | 0.079 | 0.122 |  | 0.683                                                                                                                                                                                                                                                              | 0.260 | 0.079 | 0.140 |  |
| 26 | 0.398 | 16 | 0.6437                                                                                                                                                                          | 0.2606 | 0.084 | 0.130 |  | 0.731                                                                                                                                                                                                                                                              | 0.278 | 0.084 | 0.149 |  |
| 28 | 0.424 | 14 | 0.6863                                                                                                                                                                          | 0.2778 | 0.088 | 0.139 |  | 0.779                                                                                                                                                                                                                                                              | 0.296 | 0.088 | 0.158 |  |
| 30 | 0.450 | 14 | 0.7270                                                                                                                                                                          | 0.2950 | 0.093 | 0.147 |  | 0.827                                                                                                                                                                                                                                                              | 0.315 | 0.093 | 0.167 |  |

## STANDARD SET SCREWS

| Diameter | No. of threads per inch | Diameter of root of thread                    | Diameter of tap drill                         | Dimensions of set screw heads (Hartford Mach. Sc. Co. Standard) |                |                |               |                |                |      |      |
|----------|-------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------------------------|----------------|----------------|---------------|----------------|----------------|------|------|
|          |                         |                                               |                                               | B                                                               | H              | H <sub>1</sub> | C             | M              | R              | F    | N    |
| 1        | 20                      | Same as U. S. Standard Bolt or Sharp V-Thread | Same as U. S. Standard Bolt or Sharp V-Thread | Same as diameter first column                                   | $\frac{3}{16}$ | $\frac{1}{8}$  | $\frac{1}{8}$ | $\frac{7}{32}$ | $\frac{1}{4}$  | .019 | .075 |
|          | 18                      |                                               |                                               |                                                                 | $\frac{1}{8}$  | $\frac{5}{32}$ | $\frac{1}{8}$ | $\frac{3}{8}$  | $\frac{5}{16}$ | .021 | .083 |
|          | 16                      |                                               |                                               |                                                                 | $\frac{1}{8}$  | $\frac{3}{16}$ | $\frac{1}{8}$ | $\frac{1}{2}$  | $\frac{3}{8}$  | .023 | .094 |
|          | 14                      |                                               |                                               |                                                                 | $\frac{1}{8}$  | $\frac{7}{32}$ | $\frac{1}{8}$ | $\frac{1}{2}$  | $\frac{3}{8}$  | .027 | .107 |
|          | 13                      |                                               |                                               |                                                                 | $\frac{1}{8}$  | $\frac{1}{4}$  | 1             | $\frac{1}{2}$  | $\frac{3}{8}$  | .031 | .125 |
|          | 12                      |                                               |                                               |                                                                 | $\frac{1}{8}$  | $\frac{9}{32}$ | $\frac{1}{8}$ | $\frac{1}{2}$  | $\frac{3}{8}$  | .032 | .125 |
|          | 11                      |                                               |                                               |                                                                 | $\frac{1}{8}$  | $\frac{1}{2}$  | $\frac{1}{8}$ | $\frac{1}{2}$  | $\frac{3}{8}$  | .034 | .130 |
|          | 10                      |                                               |                                               |                                                                 | $\frac{1}{8}$  | $\frac{1}{2}$  | $\frac{1}{8}$ | $\frac{1}{2}$  | $\frac{3}{8}$  | .037 | .150 |
| 1        | 9                       | Same as U. S. Standard Bolt or Sharp V-Thread | Same as U. S. Standard Bolt or Sharp V-Thread | Same as diameter first column                                   | $\frac{1}{8}$  | $\frac{1}{2}$  | $\frac{1}{8}$ | $\frac{1}{2}$  | $\frac{3}{8}$  | .041 | .166 |
|          | 8                       |                                               |                                               |                                                                 | $\frac{1}{8}$  | $\frac{1}{2}$  | $\frac{1}{8}$ | $\frac{1}{2}$  | $\frac{3}{8}$  | .047 | .187 |



## ELEMENTS OF THE ACME STANDARD THREAD

| Threads per Inch | Depth of Thread | Width of Flat at Top of Thread | Width of Flat at Root of Thread |
|------------------|-----------------|--------------------------------|---------------------------------|
| 1                | 0.5100          | 0.3707                         | 0.3655                          |
| 1½               | 0.3433          | 0.2471                         | 0.2419                          |
| 2                | 0.2600          | 0.1853                         | 0.1801                          |
| 2½               | 0.2100          | 0.1483                         | 0.1431                          |
| 3                | 0.1767          | 0.1236                         | 0.1184                          |
| 3½               | 0.1529          | 0.1059                         | 0.1007                          |
| 4                | 0.1350          | 0.0927                         | 0.0875                          |
| 4½               | 0.1211          | 0.0824                         | 0.0772                          |
| 5                | 0.1100          | 0.0741                         | 0.0689                          |
| 5½               | 0.1009          | 0.0674                         | 0.0622                          |
| 6                | 0.0933          | 0.0618                         | 0.0566                          |
| 7                | 0.0814          | 0.0530                         | 0.0478                          |
| 8                | 0.0725          | 0.0463                         | 0.0411                          |
| 9                | 0.0656          | 0.0412                         | 0.0360                          |
| 10               | 0.0600          | 0.0371                         | 0.0319                          |
| 12               | 0.0517          | 0.0309                         | 0.0257                          |



## Wire Gages

There has come about, through lack of standardization, a great deal of confusion concerning wire gages to be specified on the engineer's drawings. Until wire manufacturers have agreed to some national standard it would be well to specify on the drawing the exact diameter of the wire wanted. In the case of steel wires, the Bureau of Standards at Washington has recommended that the American Steel and Wire Co.'s gage be adopted as the Steel Wire Gage. This gage is given in the table below in decimals of an inch, and is the same as the Washburn & Moen gage. When there is danger of confusion with the British gage, it should be called the United States Steel Wire Gage.

In the case of copper wire, the American Wire Gage is standard throughout the United States and is the same as the Brown & Sharpe gage. It is also given in the table below in decimals of an inch.

## Sheet and Plate Metal Gage

Congress legalized the United States Standard Gage for sheet and plate iron and steel, March 3, 1893. The various gage sizes are given in decimals of an inch in the table below.

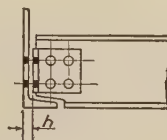
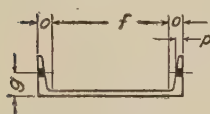
## WIRE AND SHEET METAL GAGES

| No. of<br>gage | Steel wire<br>gage | American<br>copper or<br>B. & S.<br>wire gage | British<br>imperial<br>wire gage | U. S. St'd.<br>gage for<br>plate | No. of<br>gage | Steel wire<br>gage | American<br>wire gage | British<br>imperial<br>wire gage | U. S. St'd.<br>gage for<br>plate |
|----------------|--------------------|-----------------------------------------------|----------------------------------|----------------------------------|----------------|--------------------|-----------------------|----------------------------------|----------------------------------|
| 0000000        | 0.4900             | .....                                         | 0.5000                           | 0.5000                           | 23             | 0.0258             | 0.0226                | 0.0240                           | 0.0281                           |
| 000000         | 0.4615             | 0.5800                                        | 0.4640                           | 0.4688                           | 24             | 0.0230             | 0.0201                | 0.0220                           | 0.0250                           |
| 00000          | 0.4305             | 0.5165                                        | 0.4320                           | 0.4375                           | 25             | 0.0204             | 0.0179                | 0.0200                           | 0.0219                           |
| 0000           | 0.3938             | 0.4600                                        | 0.4000                           | 0.4063                           | 26             | 0.0181             | 0.0159                | 0.0180                           | 0.0188                           |
| 000            | 0.3625             | 0.4096                                        | 0.3720                           | 0.3750                           | 27             | 0.0173             | 0.0142                | 0.0164                           | 0.0172                           |
| 00             | 0.3310             | 0.3648                                        | 0.3480                           | 0.3438                           | 28             | 0.0162             | 0.0126                | 0.0148                           | 0.0156                           |
| 0              | 0.3065             | 0.3249                                        | 0.3240                           | 0.3125                           | 29             | 0.0150             | 0.0113                | 0.0136                           | 0.0141                           |
| 1              | 0.2830             | 0.2893                                        | 0.3000                           | 0.2813                           | 30             | 0.0140             | 0.0100                | 0.0124                           | 0.0125                           |
| 2              | 0.2625             | 0.2576                                        | 0.2760                           | 0.2656                           | 31             | 0.0132             | 0.0089                | 0.0116                           | 0.0109                           |
| 3              | 0.2437             | 0.2294                                        | 0.2520                           | 0.2500                           | 32             | 0.0128             | 0.0080                | 0.0108                           | 0.0102                           |
| 4              | 0.2253             | 0.2043                                        | 0.2320                           | 0.2344                           | 33             | 0.0118             | 0.0071                | 0.0100                           | 0.0094                           |
| 5              | 0.2070             | 0.1819                                        | 0.2120                           | 0.2188                           | 34             | 0.0104             | 0.0063                | 0.0092                           | 0.0086                           |
| 6              | 0.1920             | 0.1620                                        | 0.1920                           | 0.2031                           | 35             | 0.0095             | 0.0056                | 0.0084                           | 0.0078                           |
| 7              | 0.1770             | 0.1443                                        | 0.1760                           | 0.1875                           | 36             | 0.0090             | 0.0050                | 0.0076                           | 0.0070                           |
| 8              | 0.1620             | 0.1285                                        | 0.1600                           | 0.1719                           | 37             | 0.0085             | 0.0045                | 0.0068                           | 0.0066                           |
| 9              | 0.1483             | 0.1144                                        | 0.1440                           | 0.1563                           | 38             | 0.0080             | 0.0040                | 0.0060                           | 0.0063                           |
| 10             | 0.1350             | 0.1019                                        | 0.1280                           | 0.1406                           | 39             | 0.0075             | 0.0035                | 0.0052                           | .....                            |
| 11             | 0.1205             | 0.0907                                        | 0.1160                           | 0.1250                           | 40             | 0.0070             | 0.0031                | 0.0048                           | .....                            |
| 12             | 0.1055             | 0.0808                                        | 0.1040                           | 0.1094                           | 41             | 0.0066             | 0.0028                | 0.0044                           | .....                            |
| 13             | 0.0915             | 0.0720                                        | 0.0920                           | 0.0938                           | 42             | 0.0062             | 0.0025                | 0.0040                           | .....                            |
| 14             | 0.0800             | 0.0641                                        | 0.0800                           | 0.0781                           | 43             | 0.0060             | 0.0022                | 0.0036                           | .....                            |
| 15             | 0.0720             | 0.0571                                        | 0.0720                           | 0.0703                           | 44             | 0.0058             | 0.0020                | 0.0032                           | .....                            |
| 16             | 0.0625             | 0.0508                                        | 0.0640                           | 0.0625                           | 45             | 0.0055             | 0.00176               | 0.0028                           | .....                            |
| 17             | 0.0540             | 0.0453                                        | 0.0560                           | 0.0563                           | 46             | 0.0052             | 0.00157               | 0.0024                           | .....                            |
| 18             | 0.0475             | 0.0403                                        | 0.0480                           | 0.0500                           | 47             | 0.0050             | 0.00140               | 0.0020                           | .....                            |
| 19             | 0.0410             | 0.0359                                        | 0.0400                           | 0.0438                           | 48             | 0.0048             | 0.00124               | 0.0016                           | .....                            |
| 20             | 0.0348             | 0.0320                                        | 0.0360                           | 0.0375                           | 49             | 0.0046             | 0.00099               | 0.0012                           | .....                            |
| 21             | 0.0317             | 0.0285                                        | 0.0320                           | 0.0344                           | 50             | 0.0044             | 0.00088               | 0.0010                           | .....                            |
| 22             | 0.0286             | 0.0253                                        | 0.0280                           | 0.0313                           |                |                    |                       |                                  |                                  |

RIVET SPACING  
(Cambria Handbook)  
All dimensions in inches

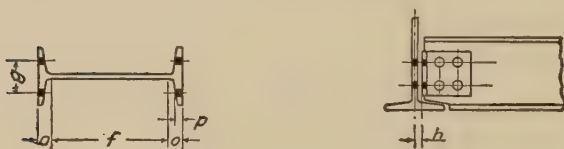
| Size of rivet  | Minimum pitch  |                | Maximum pitch at ends of compression members | Minimum distance from edge of piece to center of rivet hole |                | Maximum pitch in line of stress for plate and shape members |
|----------------|----------------|----------------|----------------------------------------------|-------------------------------------------------------------|----------------|-------------------------------------------------------------|
|                | Allowable      | Preferable     |                                              | Sheared edge                                                | Rolled edge    |                                                             |
| $\frac{1}{4}$  | $\frac{3}{4}$  |                |                                              |                                                             |                |                                                             |
| $\frac{3}{8}$  | $1\frac{1}{8}$ |                |                                              |                                                             |                |                                                             |
| $\frac{1}{2}$  | $1\frac{1}{2}$ | $1\frac{3}{4}$ |                                              | 1                                                           | $\frac{7}{8}$  | 4                                                           |
| $\frac{5}{8}$  | $1\frac{7}{8}$ | 2              | $2\frac{1}{2}$                               | $1\frac{1}{8}$                                              | 1              | $4\frac{1}{2}$                                              |
| $\frac{3}{4}$  | $2\frac{1}{4}$ | $2\frac{1}{2}$ | 3                                            | $1\frac{1}{4}$                                              | $1\frac{1}{8}$ | 6                                                           |
| $\frac{7}{8}$  | 2              | 3              | $3\frac{1}{2}$                               | $1\frac{1}{2}$                                              | $1\frac{1}{4}$ | 6                                                           |
| 1              |                |                | 4                                            |                                                             |                |                                                             |
| $1\frac{1}{8}$ | $3\frac{3}{8}$ |                | $4\frac{1}{2}$                               |                                                             |                |                                                             |

STANDARD GAGES AND DIMENSIONS FOR CHANNELS  
(Carnegie Pocket Companion)



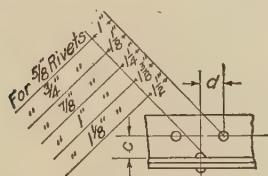
| Depth of channel | Weight per foot | Flange width   | Web thickness  | $\frac{1}{2}$ Web thickness | Gage g         | Grip p         | Distance        |                |                | Max. rivet in flange |
|------------------|-----------------|----------------|----------------|-----------------------------|----------------|----------------|-----------------|----------------|----------------|----------------------|
|                  |                 |                |                |                             |                |                | f               | o              | h              |                      |
| In.              | In.             | In.            | In.            | In.                         | In.            | In.            | In.             | In.            | In.            | In.                  |
| 15               | 33.9            | $3\frac{3}{8}$ | $3\frac{5}{8}$ | $3\frac{1}{8}$              | 2              | $5\frac{5}{8}$ | $12\frac{1}{4}$ | $1\frac{3}{8}$ | $1\frac{1}{2}$ | $7\frac{7}{8}$       |
| 13               | 31.8            | 4              | $3\frac{3}{8}$ | $3\frac{1}{8}$              | $2\frac{1}{2}$ | $5\frac{1}{8}$ | $10\frac{1}{2}$ | $1\frac{1}{4}$ | $1\frac{1}{8}$ | $7\frac{1}{8}$       |
| 12               | 20.7            | 3              | $3\frac{1}{8}$ | $3\frac{1}{8}$              | $2\frac{3}{4}$ | $5\frac{1}{2}$ | 10              | 1              | $1\frac{1}{8}$ | $7\frac{1}{8}$       |
| 10               | 15.3            | $2\frac{5}{8}$ | $3\frac{1}{4}$ | $3\frac{1}{8}$              | $2\frac{1}{2}$ | $5\frac{1}{8}$ | $8\frac{1}{4}$  | $7\frac{7}{8}$ | $1\frac{1}{8}$ | $7\frac{1}{8}$       |
| 9                | 13.4            | $2\frac{3}{8}$ | $3\frac{1}{4}$ | $3\frac{1}{8}$              | $2\frac{1}{2}$ | $5\frac{1}{8}$ | $7\frac{1}{4}$  | $7\frac{7}{8}$ | $1\frac{1}{8}$ | $7\frac{1}{8}$       |
| 8                | 11.5            | $2\frac{1}{8}$ | $3\frac{1}{4}$ | $3\frac{1}{8}$              | $2\frac{1}{2}$ | $5\frac{1}{8}$ | $6\frac{1}{4}$  | $7\frac{7}{8}$ | $1\frac{1}{8}$ | $7\frac{1}{8}$       |
| 7                | 9.8             | $2\frac{1}{8}$ | $3\frac{1}{4}$ | $3\frac{1}{8}$              | $2\frac{1}{2}$ | $5\frac{1}{8}$ | $5\frac{1}{2}$  | $7\frac{7}{8}$ | $1\frac{1}{8}$ | $7\frac{1}{8}$       |
| 6                | 8.2             | $1\frac{7}{8}$ | $3\frac{1}{4}$ | $3\frac{1}{8}$              | $2\frac{1}{2}$ | $5\frac{1}{8}$ | $4\frac{1}{2}$  | $7\frac{7}{8}$ | $1\frac{1}{8}$ | $7\frac{1}{8}$       |
| 5                | 6.7             | $1\frac{3}{4}$ | $3\frac{1}{4}$ | $3\frac{1}{8}$              | $2\frac{1}{2}$ | $5\frac{1}{8}$ | $3\frac{3}{4}$  | $7\frac{7}{8}$ | $1\frac{1}{8}$ | $7\frac{1}{8}$       |
| 4                | 5.4             | $1\frac{3}{8}$ | $3\frac{1}{4}$ | $3\frac{1}{8}$              | $2\frac{1}{2}$ | $5\frac{1}{8}$ | $2\frac{3}{4}$  | $7\frac{7}{8}$ | $1\frac{1}{8}$ | $7\frac{1}{8}$       |
| 3                | 4.1             | $1\frac{1}{8}$ | $3\frac{1}{4}$ | $3\frac{1}{8}$              | $2\frac{1}{2}$ | $5\frac{1}{8}$ | $1\frac{1}{4}$  | $7\frac{7}{8}$ | $1\frac{1}{8}$ | $7\frac{1}{8}$       |

STANDARD GAGES AND DIMENSIONS FOR BEAMS  
(Carnegie Pocket Companion)



| Depth<br>of<br>beam | Weight<br>per<br>foot | Flange<br>width | Web<br>thick-<br>ness | $\frac{1}{2}$ Web<br>thick-<br>ness | Gage<br>g       | Grip<br>p      | Distance         |                  |                | Max.<br>rivet<br>in<br>flange |
|---------------------|-----------------------|-----------------|-----------------------|-------------------------------------|-----------------|----------------|------------------|------------------|----------------|-------------------------------|
|                     |                       |                 |                       |                                     |                 |                | f                | o                | h              |                               |
| In.                 | In.                   | In.             | In.                   | In.                                 | In.             | In.            | In.              | In.              | In.            | In.                           |
| 27                  | 90.0                  | 9               | $1\frac{3}{4}$        | $\frac{1}{4}$                       | 5               | $\frac{3}{4}$  | 22 $\frac{1}{2}$ | 21 $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{7}{8}$                 |
| 24                  | 79.9                  | 7               | $\frac{1}{2}$         | $\frac{1}{4}$                       | 4               | $\frac{7}{8}$  | 20 $\frac{3}{4}$ | 19 $\frac{1}{2}$ | $\frac{5}{16}$ | $\frac{7}{8}$                 |
| 21                  | 60.4                  | 8 $\frac{1}{4}$ | $\frac{3}{16}$        | $\frac{1}{16}$                      | 4               | $\frac{1}{8}$  | 17 $\frac{1}{2}$ | 16 $\frac{3}{4}$ | $\frac{1}{4}$  | $\frac{7}{8}$                 |
| 20                  | 65.4                  | 6 $\frac{1}{4}$ | $\frac{1}{2}$         | $\frac{1}{4}$                       | 4               | $\frac{1}{8}$  | 17               | 16 $\frac{1}{2}$ | $\frac{5}{16}$ | $\frac{7}{8}$                 |
| 18                  | 54.7                  | 6               | $\frac{7}{16}$        | $\frac{1}{4}$                       | 3 $\frac{3}{4}$ | $\frac{3}{8}$  | 15 $\frac{1}{4}$ | 14 $\frac{1}{2}$ | $\frac{5}{16}$ | $\frac{7}{8}$                 |
| 15                  | 42.9                  | 5 $\frac{1}{2}$ | $\frac{7}{16}$        | $\frac{3}{16}$                      | 3 $\frac{1}{2}$ | $\frac{1}{8}$  | 12 $\frac{1}{2}$ | 11 $\frac{3}{4}$ | $\frac{5}{16}$ | $\frac{7}{8}$                 |
| 12                  | 31.8                  | 5               | $\frac{3}{8}$         | $\frac{3}{16}$                      | 3               | $\frac{1}{8}$  | 9                | 8 $\frac{1}{4}$  | $\frac{1}{4}$  | $\frac{3}{4}$                 |
| 10                  | 25.4                  | 4 $\frac{5}{8}$ | $\frac{5}{16}$        | $\frac{1}{8}$                       | 2 $\frac{3}{4}$ | $\frac{1}{2}$  | 8                | 7 $\frac{1}{4}$  | $\frac{1}{4}$  | $\frac{3}{4}$                 |
| 9                   | 21.8                  | 4 $\frac{3}{8}$ | $\frac{5}{16}$        | $\frac{1}{8}$                       | 2 $\frac{1}{2}$ | $\frac{1}{2}$  | 7                | 6 $\frac{1}{4}$  | $\frac{3}{16}$ | $\frac{3}{4}$                 |
| 8                   | 18.4                  | 4               | $\frac{1}{4}$         | $\frac{1}{8}$                       | 2 $\frac{1}{4}$ | $\frac{7}{16}$ | 6 $\frac{1}{4}$  | 5 $\frac{1}{4}$  | $\frac{3}{16}$ | $\frac{3}{4}$                 |
| 7                   | 15.3                  | 3 $\frac{5}{8}$ | $\frac{1}{4}$         | $\frac{1}{8}$                       | 2 $\frac{1}{4}$ | $\frac{3}{8}$  | 5 $\frac{1}{4}$  | 4 $\frac{1}{2}$  | $\frac{3}{16}$ | $\frac{3}{4}$                 |
| 6                   | 12.5                  | 3 $\frac{3}{8}$ | $\frac{1}{4}$         | $\frac{1}{8}$                       | 2               | $\frac{3}{8}$  | 4                | 3 $\frac{1}{2}$  | $\frac{3}{16}$ | $\frac{3}{4}$                 |
| 5                   | 10.0                  | 3               | $\frac{3}{8}$         | $\frac{1}{8}$                       | 1 $\frac{3}{4}$ | $\frac{3}{8}$  | 3                | 2 $\frac{1}{2}$  | $\frac{3}{16}$ | $\frac{3}{4}$                 |
| 4                   | 7.7                   | 2 $\frac{5}{8}$ | $\frac{3}{8}$         | $\frac{1}{8}$                       | 1 $\frac{1}{2}$ | $\frac{5}{16}$ | 2 $\frac{3}{4}$  | 2 $\frac{1}{4}$  | $\frac{3}{16}$ | $\frac{3}{4}$                 |
| 3                   | 5.7                   | 2 $\frac{3}{8}$ | $\frac{3}{8}$         | $\frac{1}{16}$                      | 1 $\frac{1}{2}$ | $\frac{5}{16}$ | 1 $\frac{3}{4}$  | 1 $\frac{1}{4}$  | $\frac{1}{8}$  | $\frac{3}{8}$                 |

RIVET SPACING  
(American Bridge Co. Standard)  
Minimum Stagger for Rivets



| Diameter<br>of rivets<br>Inches | Minimum stagger, d, inches |                 |                  |                  |                  |                 |                 |                 |                 |                  |                 |                  |                 |                  |                 |
|---------------------------------|----------------------------|-----------------|------------------|------------------|------------------|-----------------|-----------------|-----------------|-----------------|------------------|-----------------|------------------|-----------------|------------------|-----------------|
|                                 | c, inches                  |                 |                  |                  |                  |                 |                 |                 |                 |                  |                 |                  |                 |                  |                 |
|                                 | $1\frac{1}{8}$             | $1\frac{1}{16}$ | $1\frac{1}{4}$   | $1\frac{5}{16}$  | $1\frac{3}{8}$   | $1\frac{7}{16}$ | $1\frac{1}{2}$  | $1\frac{9}{16}$ | $1\frac{5}{8}$  | $1\frac{11}{16}$ | $1\frac{3}{4}$  | $1\frac{13}{16}$ | $1\frac{7}{8}$  | $1\frac{15}{16}$ | $2\frac{1}{16}$ |
| $\frac{5}{8}$                   | $\frac{15}{16}$            | $\frac{7}{8}$   | $\frac{13}{16}$  | $\frac{11}{16}$  | $\frac{1}{2}$    | $\frac{5}{16}$  | 0               | $\frac{3}{4}$   | $\frac{9}{16}$  | $\frac{3}{8}$    | 0               | $\frac{1}{2}$    | $\frac{5}{8}$   | $\frac{7}{8}$    | $\frac{1}{2}$   |
| $\frac{3}{4}$                   | $\frac{1}{4}$              | $\frac{3}{8}$   | $\frac{1}{8}$    | $\frac{1}{16}$   | $\frac{1}{4}$    | $\frac{3}{8}$   | $\frac{1}{2}$   | $\frac{1}{4}$   | $\frac{1}{8}$   | $\frac{1}{16}$   | $\frac{1}{8}$   | $\frac{1}{16}$   | $\frac{1}{8}$   | $\frac{1}{16}$   | $\frac{1}{8}$   |
| $\frac{1}{2}$                   | $\frac{1}{2}$              | $\frac{1}{4}$   | $\frac{1}{8}$    | $\frac{1}{16}$   | $\frac{1}{4}$    | $\frac{3}{8}$   | $\frac{1}{2}$   | $\frac{1}{4}$   | $\frac{1}{8}$   | $\frac{1}{16}$   | $\frac{1}{8}$   | $\frac{1}{16}$   | $\frac{1}{8}$   | $\frac{1}{16}$   | $\frac{1}{8}$   |
| $\frac{1}{8}$                   | $2\frac{1}{16}$            | 2               | $1\frac{15}{16}$ | $1\frac{13}{16}$ | $1\frac{11}{16}$ | $1\frac{9}{16}$ | $1\frac{7}{16}$ | $1\frac{5}{16}$ | $1\frac{3}{16}$ | $1\frac{1}{16}$  | $1\frac{1}{16}$ | $1\frac{1}{16}$  | $1\frac{1}{16}$ | $1\frac{1}{16}$  | $1\frac{1}{16}$ |

GAGES FOR ANGLES, INCHES



| Leg           | 8              | 7              | 6              | 5              | 4              | $3\frac{1}{2}$ | 3              | $2\frac{1}{2}$ | 2              | $1\frac{1}{2}$ | $1\frac{1}{4}$ | $1\frac{1}{8}$ | $1\frac{1}{16}$ | 1             | $\frac{3}{4}$ |
|---------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------|---------------|---------------|
| $g^1$         | $4\frac{1}{2}$ | 4              | $3\frac{1}{2}$ | $3\frac{1}{2}$ | $2\frac{1}{2}$ | 2              | $1\frac{3}{4}$ | $1\frac{3}{8}$ | $1\frac{1}{8}$ | 1              | $\frac{7}{8}$  | $\frac{7}{8}$  | $\frac{3}{4}$   | $\frac{5}{8}$ | $\frac{1}{2}$ |
| $g^2$         | 3              | $2\frac{1}{2}$ | $2\frac{1}{2}$ | $2\frac{1}{2}$ | $1\frac{3}{4}$ |                |                |                |                |                |                |                |                 |               |               |
| $g^3$         | 3              | 3              | $2\frac{1}{2}$ | $2\frac{1}{2}$ | $1\frac{3}{4}$ |                |                |                |                |                |                |                |                 |               |               |
| Max.<br>rivet | $1\frac{1}{8}$ | 1              | $\frac{7}{8}$  | $\frac{7}{8}$  | $\frac{7}{8}$  | $\frac{7}{8}$  | $\frac{7}{8}$  | $\frac{3}{4}$  | $\frac{3}{8}$  | $\frac{1}{2}$  | $\frac{3}{8}$  | $\frac{3}{8}$  | $\frac{3}{8}$   | $\frac{1}{4}$ | $\frac{1}{4}$ |

## METRIC EQUIVALENTS

| Mm. to inches |     |             |     | Inches to mm.           |     |                         |     |
|---------------|-----|-------------|-----|-------------------------|-----|-------------------------|-----|
| Mm.           | In. | Mm.         | In. | In.                     | Mm. | In.                     | Mm. |
| 1 = .0394     |     | 17 = .6693  |     | $\frac{1}{32}$ = .79    |     | $\frac{17}{32}$ = 13.49 |     |
| 2 = .0787     |     | 18 = .7087  |     | $\frac{1}{16}$ = 1.58   |     | $\frac{9}{16}$ = 14.28  |     |
| 3 = .1181     |     | 19 = .7480  |     | $\frac{3}{32}$ = 2.38   |     | $\frac{19}{32}$ = 15.08 |     |
| 4 = .1575     |     | 20 = .7874  |     | $\frac{1}{8}$ = 3.17    |     | $\frac{5}{8}$ = 15.87   |     |
| 5 = .1968     |     | 21 = .8268  |     | $\frac{3}{16}$ = 3.96   |     | $\frac{21}{16}$ = 16.66 |     |
| 6 = .2362     |     | 22 = .8661  |     | $\frac{1}{4}$ = 4.76    |     | $\frac{11}{16}$ = 17.46 |     |
| 7 = .2756     |     | 23 = .9055  |     | $\frac{5}{16}$ = 5.55   |     | $\frac{23}{16}$ = 18.25 |     |
| 8 = .3150     |     | 24 = .9449  |     | $\frac{3}{8}$ = 6.34    |     | $\frac{24}{16}$ = 19.04 |     |
| 9 = .3543     |     | 25 = .9843  |     | $\frac{7}{16}$ = 7.14   |     | $\frac{25}{16}$ = 19.84 |     |
| 10 = .3937    |     | 26 = 1.0236 |     | $\frac{1}{2}$ = 7.93    |     | $\frac{26}{16}$ = 20.63 |     |
| 11 = .4331    |     | 27 = 1.0630 |     | $\frac{5}{8}$ = 8.73    |     | $\frac{27}{16}$ = 21.43 |     |
| 12 = .4724    |     | 28 = 1.1024 |     | $\frac{3}{4}$ = 9.52    |     | $\frac{28}{16}$ = 22.22 |     |
| 13 = .5118    |     | 29 = 1.1417 |     | $\frac{13}{16}$ = 10.31 |     | $\frac{29}{16}$ = 23.01 |     |
| 14 = .5512    |     | 30 = 1.1811 |     | $\frac{7}{8}$ = 11.11   |     | $\frac{30}{16}$ = 23.81 |     |
| 15 = .5906    |     | 31 = 1.2205 |     | $\frac{15}{16}$ = 11.90 |     | $\frac{31}{16}$ = 24.60 |     |
| 16 = .6299    |     | 32 = 1.2598 |     | $\frac{1}{2}$ = 12.69   |     | 1 = 25.39               |     |

## METRIC CONVERSION TABLES

Inches to Centimeters — 1 in. = 2.540005 cm.

| Units<br>tens | 0       | 1       | 2       | 3       | 4       | 5       | 6       | 7       | 8       | 9       |
|---------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| 0             |         | 2.540   | 5.080   | 7.620   | 10.160  | 12.700  | 15.240  | 17.780  | 20.320  | 22.860  |
| 1             | 25.400  | 27.940  | 30.480  | 33.020  | 35.560  | 38.100  | 40.640  | 43.180  | 45.720  | 48.260  |
| 2             | 50.800  | 53.340  | 55.880  | 58.420  | 60.960  | 63.500  | 66.040  | 68.580  | 71.120  | 73.660  |
| 3             | 76.200  | 78.740  | 81.280  | 83.820  | 86.360  | 88.900  | 91.440  | 93.980  | 96.520  | 99.060  |
| 4             | 101.600 | 104.140 | 106.680 | 109.220 | 111.760 | 114.300 | 116.840 | 119.380 | 121.920 | 124.460 |
| 5             | 127.000 | 129.540 | 132.080 | 134.620 | 137.160 | 139.700 | 142.240 | 144.780 | 147.320 | 149.860 |
| 6             | 152.400 | 154.940 | 157.480 | 160.020 | 162.560 | 165.100 | 167.640 | 170.180 | 172.720 | 175.260 |
| 7             | 177.800 | 180.340 | 182.880 | 185.420 | 187.960 | 190.500 | 193.040 | 195.580 | 198.120 | 200.660 |
| 8             | 203.200 | 205.740 | 208.280 | 210.820 | 213.360 | 215.900 | 218.440 | 220.980 | 223.520 | 226.060 |
| 9             | 228.600 | 231.140 | 233.680 | 236.220 | 238.760 | 241.300 | 243.840 | 246.380 | 248.920 | 251.460 |

Centimeters to Inches — 1 cm. = 0.3937 in.

| Units<br>tens | 0       | 1       | 2       | 3       | 4       | 5       | 6       | 7       | 8       | 9       |
|---------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| 0             |         | 0.3937  | 0.7874  | 1.1811  | 1.5748  | 1.9685  | 2.3622  | 2.7559  | 3.1496  | 3.5433  |
| 1             | 3.9370  | 4.3307  | 4.7244  | 5.1181  | 5.5118  | 5.9055  | 6.2992  | 6.6929  | 7.0866  | 7.4803  |
| 2             | 7.8740  | 8.2677  | 8.6614  | 9.0551  | 9.4488  | 9.8425  | 10.2362 | 10.6299 | 11.0236 | 11.4173 |
| 3             | 11.8110 | 12.2047 | 12.5984 | 12.9921 | 13.3858 | 13.7795 | 14.1732 | 14.5669 | 14.9606 | 15.3543 |
| 4             | 15.7480 | 16.1417 | 16.5354 | 16.9291 | 17.3228 | 17.7165 | 18.1102 | 18.5039 | 18.8976 | 19.2913 |
| 5             | 19.6850 | 20.0787 | 20.4724 | 20.8661 | 21.2598 | 21.6535 | 22.0472 | 22.4409 | 22.8346 | 23.2283 |
| 6             | 23.6220 | 24.0157 | 24.4094 | 24.8031 | 25.1968 | 25.5905 | 25.9842 | 26.3779 | 26.7716 | 27.1653 |
| 7             | 27.5590 | 27.9527 | 28.3464 | 28.7401 | 29.1338 | 29.5275 | 29.9212 | 30.3149 | 30.7086 | 31.1023 |
| 8             | 31.4960 | 31.8897 | 32.2834 | 32.6671 | 33.0708 | 33.4645 | 33.8582 | 34.2519 | 34.6456 | 35.0393 |
| 9             | 35.4330 | 35.8267 | 36.2204 | 36.6141 | 37.0078 | 37.4015 | 37.7952 | 38.1889 | 38.5826 | 38.9763 |



## DECIMAL EQUIVALENTS OF FRACTIONS OF AN INCH

| 1-32 | 1-64 | Decimal | Fraction | 1-32 | 1-64 | Decimal | Fraction |
|------|------|---------|----------|------|------|---------|----------|
| 1    | 1    | .015625 | 1-16     | 17   | 33   | .515625 | 9-16     |
|      | 2    | .03125  |          |      | 34   | .53125  |          |
|      | 3    | .046875 |          |      | 35   | .546875 |          |
| 2    | 4    | .0625   |          | 18   | 36   | .5625   |          |
| 3    | 5    | .078125 | 1-8      | 19   | 37   | .578125 | 5-8      |
|      | 6    | .09375  |          |      | 38   | .59375  |          |
|      | 7    | .109375 |          |      | 39   | .609375 |          |
| 4    | 8    | .125    |          | 20   | 40   | .625    |          |
| 5    | 9    | .140625 | 3-16     | 21   | 41   | .640625 | 11-16    |
|      | 10   | .15625  |          |      | 42   | .65625  |          |
|      | 11   | .171875 |          |      | 43   | .671875 |          |
| 6    | 12   | .1875   |          | 22   | 44   | .6875   |          |
| 7    | 13   | .203125 | 1-4      | 23   | 45   | .703125 | 3-4      |
|      | 14   | .21875  |          |      | 46   | .71875  |          |
|      | 15   | .234375 |          |      | 47   | .734375 |          |
| 8    | 16   | .25     |          | 24   | 48   | .75     |          |
| 9    | 17   | .265625 | 5-16     | 25   | 49   | .765625 | 13-16    |
|      | 18   | .28125  |          |      | 50   | .78125  |          |
|      | 19   | .296875 |          |      | 51   | .796875 |          |
| 10   | 20   | .3125   |          | 26   | 52   | .8125   |          |
| 11   | 21   | .328125 | 3-8      | 27   | 53   | .828125 | 7-8      |
|      | 22   | .34375  |          |      | 54   | .84375  |          |
|      | 23   | .359375 |          |      | 55   | .859375 |          |
| 12   | 24   | .375    |          | 28   | 56   | .875    |          |
| 13   | 25   | .390625 | 7-16     | 29   | 57   | .890625 | 15-16    |
|      | 26   | .40625  |          |      | 58   | .90625  |          |
|      | 27   | .421875 |          |      | 59   | .921875 |          |
| 14   | 28   | .4375   |          | 30   | 60   | .9375   |          |
| 15   | 29   | .453125 | 1-2      | 31   | 61   | .953125 | 1        |
|      | 30   | .46875  |          |      | 62   | .96875  |          |
|      | 31   | .48375  |          |      | 63   | .984375 |          |
| 16   | 32   | .5      |          | 32   | 64   | 1       |          |



## NATURAL TRIGONOMETRIC FUNCTIONS

| Degrees | COSINES |         |         |         |         |         |         | Sines   |
|---------|---------|---------|---------|---------|---------|---------|---------|---------|
|         | 0'      | 10'     | 20'     | 30'     | 40'     | 50'     | 60'     |         |
| 0       | 1.00000 | 1.00000 | 0.99998 | 0.99996 | 0.99993 | 0.99989 | 0.99985 | 89      |
| 1       | 0.99985 | 0.99979 | 0.99973 | 0.99966 | 0.99958 | 0.99949 | 0.99939 | 88      |
| 2       | 0.99939 | 0.99929 | 0.99917 | 0.99905 | 0.99892 | 0.99878 | 0.99863 | 87      |
| 3       | 0.99863 | 0.99847 | 0.99831 | 0.99813 | 0.99795 | 0.99776 | 0.99756 | 86      |
| 4       | 0.99756 | 0.99736 | 0.99714 | 0.99692 | 0.99668 | 0.99644 | 0.99619 | 85      |
| 5       | 0.99619 | 0.99594 | 0.99567 | 0.99540 | 0.99511 | 0.99482 | 0.99452 | 84      |
| 6       | 0.99452 | 0.99421 | 0.99390 | 0.99357 | 0.99324 | 0.99290 | 0.99255 | 83      |
| 7       | 0.99255 | 0.99219 | 0.99182 | 0.99144 | 0.99106 | 0.99067 | 0.99027 | 82      |
| 8       | 0.99027 | 0.98986 | 0.98944 | 0.98902 | 0.98858 | 0.98814 | 0.98769 | 81      |
| 9       | 0.98769 | 0.98723 | 0.98676 | 0.98629 | 0.98580 | 0.98531 | 0.98481 | 80      |
| 10      | 0.98481 | 0.98430 | 0.98378 | 0.98325 | 0.98272 | 0.98218 | 0.98163 | 79      |
| 11      | 0.98163 | 0.98107 | 0.98050 | 0.97992 | 0.97934 | 0.97875 | 0.97815 | 78      |
| 12      | 0.97815 | 0.97754 | 0.97692 | 0.97630 | 0.97566 | 0.97502 | 0.97437 | 77      |
| 13      | 0.97437 | 0.97371 | 0.97304 | 0.97237 | 0.97169 | 0.97100 | 0.97030 | 76      |
| 14      | 0.97030 | 0.96959 | 0.96887 | 0.96815 | 0.96742 | 0.96667 | 0.96593 | 75      |
| 15      | 0.96593 | 0.96517 | 0.96440 | 0.96363 | 0.96285 | 0.96206 | 0.96126 | 74      |
| 16      | 0.96126 | 0.96046 | 0.95964 | 0.95882 | 0.95799 | 0.95715 | 0.95630 | 73      |
| 17      | 0.95630 | 0.95545 | 0.95459 | 0.95372 | 0.95284 | 0.95195 | 0.95106 | 72      |
| 18      | 0.95106 | 0.95015 | 0.94924 | 0.94832 | 0.94740 | 0.94646 | 0.94552 | 71      |
| 19      | 0.94552 | 0.94457 | 0.94361 | 0.94264 | 0.94167 | 0.94068 | 0.93969 | 70      |
| 20      | 0.93969 | 0.93869 | 0.93769 | 0.93667 | 0.93565 | 0.93462 | 0.93358 | 69      |
| 21      | 0.93358 | 0.93253 | 0.93148 | 0.93042 | 0.92935 | 0.92827 | 0.92718 | 68      |
| 22      | 0.92718 | 0.92609 | 0.92499 | 0.92388 | 0.92276 | 0.92164 | 0.92050 | 67      |
| 23      | 0.92050 | 0.91936 | 0.91822 | 0.91706 | 0.91590 | 0.91472 | 0.91355 | 66      |
| 24      | 0.91355 | 0.91236 | 0.91116 | 0.90996 | 0.90875 | 0.90753 | 0.90631 | 65      |
| 25      | 0.90631 | 0.90507 | 0.90383 | 0.90259 | 0.90133 | 0.90007 | 0.89879 | 64      |
| 26      | 0.89879 | 0.89752 | 0.89623 | 0.89493 | 0.89363 | 0.89232 | 0.89101 | 63      |
| 27      | 0.89101 | 0.88968 | 0.88835 | 0.88701 | 0.88566 | 0.88431 | 0.88295 | 62      |
| 28      | 0.88295 | 0.88158 | 0.88020 | 0.87882 | 0.87743 | 0.87603 | 0.87462 | 61      |
| 29      | 0.87462 | 0.87321 | 0.87178 | 0.87036 | 0.86892 | 0.86748 | 0.86603 | 60      |
| 30      | 0.86603 | 0.86457 | 0.86310 | 0.86163 | 0.86015 | 0.85866 | 0.85717 | 59      |
| 31      | 0.85717 | 0.85567 | 0.85416 | 0.85264 | 0.85112 | 0.84959 | 0.84805 | 58      |
| 32      | 0.84805 | 0.84650 | 0.84495 | 0.84339 | 0.84182 | 0.84025 | 0.83867 | 57      |
| 33      | 0.83867 | 0.83708 | 0.83549 | 0.83389 | 0.83228 | 0.83066 | 0.82904 | 56      |
| 34      | 0.82904 | 0.82741 | 0.82577 | 0.82413 | 0.82248 | 0.82082 | 0.81915 | 55      |
| 35      | 0.81915 | 0.81748 | 0.81580 | 0.81412 | 0.81242 | 0.81072 | 0.80902 | 54      |
| 36      | 0.80902 | 0.80730 | 0.80558 | 0.80386 | 0.80212 | 0.80038 | 0.79864 | 53      |
| 37      | 0.79864 | 0.79688 | 0.79512 | 0.79335 | 0.79158 | 0.78980 | 0.78801 | 52      |
| 38      | 0.78801 | 0.78622 | 0.78442 | 0.78261 | 0.78079 | 0.77897 | 0.77715 | 51      |
| 39      | 0.77715 | 0.77531 | 0.77347 | 0.77162 | 0.76977 | 0.76791 | 0.76604 | 50      |
| 40      | 0.76604 | 0.76417 | 0.76229 | 0.76041 | 0.75851 | 0.75661 | 0.75471 | 49      |
| 41      | 0.75471 | 0.75280 | 0.75088 | 0.74896 | 0.74703 | 0.74509 | 0.74314 | 48      |
| 42      | 0.74314 | 0.74120 | 0.73924 | 0.73728 | 0.73531 | 0.73333 | 0.73135 | 47      |
| 43      | 0.73135 | 0.72937 | 0.72737 | 0.72537 | 0.72337 | 0.72136 | 0.71934 | 46      |
| 44      | 0.71934 | 0.71732 | 0.71529 | 0.71325 | 0.71121 | 0.70916 | 0.70711 | 45      |
| Cosines | 60'     | 50'     | 40'     | 30'     | 20'     | 10'     | 0'      | Degrees |
| SINES   |         |         |         |         |         |         |         |         |

# NATURAL TRIGONOMETRIC FUNCTIONS

| Degrees       | TANGENTS |         |         |         |         |         |         | Cotan-<br>gent |
|---------------|----------|---------|---------|---------|---------|---------|---------|----------------|
|               | 0'       | 10'     | 20'     | 30'     | 40'     | 50'     | 60'     |                |
| 0             | 0.00000  | 0.00291 | 0.00582 | 0.00873 | 0.01164 | 0.01455 | 0.01746 | 89             |
| 1             | 0.01746  | 0.02036 | 0.02328 | 0.02619 | 0.02910 | 0.03201 | 0.03492 | 88             |
| 2             | 0.03492  | 0.03783 | 0.04075 | 0.04366 | 0.04658 | 0.04949 | 0.05241 | 87             |
| 3             | 0.05241  | 0.05533 | 0.05824 | 0.06116 | 0.06408 | 0.06700 | 0.06993 | 86             |
| 4             | 0.06993  | 0.07285 | 0.07578 | 0.07870 | 0.08163 | 0.08456 | 0.08749 | 85             |
| 5             | 0.08749  | 0.09042 | 0.09335 | 0.09629 | 0.09923 | 0.10216 | 0.10510 | 84             |
| 6             | 0.10510  | 0.10805 | 0.11099 | 0.11394 | 0.11688 | 0.11983 | 0.12278 | 83             |
| 7             | 0.12278  | 0.12574 | 0.12869 | 0.13165 | 0.13461 | 0.13758 | 0.14054 | 82             |
| 8             | 0.14054  | 0.14351 | 0.14648 | 0.14945 | 0.15243 | 0.15540 | 0.15838 | 81             |
| 9             | 0.15838  | 0.16137 | 0.16435 | 0.16734 | 0.17033 | 0.17333 | 0.17633 | 80             |
| 10            | 0.17633  | 0.17933 | 0.18233 | 0.18534 | 0.18835 | 0.19136 | 0.19438 | 79             |
| 11            | 0.19438  | 0.19740 | 0.20042 | 0.20345 | 0.20648 | 0.20952 | 0.21256 | 78             |
| 12            | 0.21256  | 0.21560 | 0.21864 | 0.22169 | 0.22475 | 0.22781 | 0.23087 | 77             |
| 13            | 0.23087  | 0.23393 | 0.23700 | 0.24008 | 0.24316 | 0.24624 | 0.24933 | 76             |
| 14            | 0.24933  | 0.25242 | 0.25552 | 0.25862 | 0.26172 | 0.26483 | 0.26795 | 75             |
| 15            | 0.26795  | 0.27107 | 0.27419 | 0.27732 | 0.28046 | 0.28360 | 0.28675 | 74             |
| 16            | 0.28675  | 0.28990 | 0.29305 | 0.29621 | 0.29938 | 0.30255 | 0.30573 | 73             |
| 17            | 0.30573  | 0.30891 | 0.31210 | 0.31530 | 0.31850 | 0.32171 | 0.32492 | 72             |
| 18            | 0.32492  | 0.32814 | 0.33136 | 0.33460 | 0.33783 | 0.34108 | 0.34433 | 71             |
| 19            | 0.34433  | 0.34758 | 0.35085 | 0.35412 | 0.35740 | 0.36068 | 0.36397 | 70             |
| 20            | 0.36397  | 0.36727 | 0.37057 | 0.37388 | 0.37720 | 0.38053 | 0.38386 | 69             |
| 21            | 0.38386  | 0.38721 | 0.39055 | 0.39391 | 0.39727 | 0.40065 | 0.40403 | 68             |
| 22            | 0.40403  | 0.40741 | 0.41081 | 0.41421 | 0.41763 | 0.42105 | 0.42447 | 67             |
| 23            | 0.42447  | 0.42791 | 0.43136 | 0.43481 | 0.43828 | 0.44175 | 0.44523 | 66             |
| 24            | 0.44523  | 0.44872 | 0.45222 | 0.45573 | 0.45924 | 0.46277 | 0.46631 | 65             |
| 25            | 0.46631  | 0.46985 | 0.47341 | 0.47698 | 0.48055 | 0.48414 | 0.48773 | 64             |
| 26            | 0.48773  | 0.49134 | 0.49495 | 0.49858 | 0.50222 | 0.50587 | 0.50953 | 63             |
| 27            | 0.50953  | 0.51320 | 0.51688 | 0.52057 | 0.52427 | 0.52798 | 0.53171 | 62             |
| 28            | 0.53171  | 0.53545 | 0.53920 | 0.54296 | 0.54674 | 0.55051 | 0.55431 | 61             |
| 29            | 0.55431  | 0.55812 | 0.56194 | 0.56577 | 0.56962 | 0.57348 | 0.57735 | 60             |
| 30            | 0.57735  | 0.58124 | 0.58513 | 0.58905 | 0.59297 | 0.59691 | 0.60086 | 59             |
| 31            | 0.60086  | 0.60483 | 0.60881 | 0.61280 | 0.61681 | 0.62083 | 0.62487 | 58             |
| 32            | 0.62487  | 0.62892 | 0.63299 | 0.63707 | 0.64117 | 0.64528 | 0.64941 | 57             |
| 33            | 0.64941  | 0.65355 | 0.65771 | 0.66189 | 0.66608 | 0.67028 | 0.67451 | 56             |
| 34            | 0.67451  | 0.67875 | 0.68301 | 0.68728 | 0.69157 | 0.69588 | 0.70021 | 55             |
| 35            | 0.70021  | 0.70455 | 0.70891 | 0.71329 | 0.71769 | 0.72211 | 0.72654 | 54             |
| 36            | 0.72654  | 0.73100 | 0.73547 | 0.73996 | 0.74447 | 0.74900 | 0.75355 | 53             |
| 37            | 0.75355  | 0.75812 | 0.76272 | 0.76733 | 0.77196 | 0.77661 | 0.78129 | 52             |
| 38            | 0.78129  | 0.78598 | 0.79070 | 0.79544 | 0.80020 | 0.80498 | 0.80978 | 51             |
| 39            | 0.80978  | 0.81461 | 0.81946 | 0.82434 | 0.82923 | 0.83415 | 0.83910 | 50             |
| 40            | 0.83910  | 0.84407 | 0.84906 | 0.85408 | 0.85912 | 0.86419 | 0.86929 | 49             |
| 41            | 0.86929  | 0.87441 | 0.87955 | 0.88473 | 0.88992 | 0.89515 | 0.90040 | 48             |
| 42            | 0.90040  | 0.90569 | 0.91099 | 0.91633 | 0.92170 | 0.92709 | 0.93252 | 47             |
| 43            | 0.93252  | 0.93797 | 0.94345 | 0.94896 | 0.95451 | 0.96008 | 0.96569 | 46             |
| 44            | 0.96569  | 0.97133 | 0.97700 | 0.98270 | 0.98843 | 0.99420 | 1.00000 | 45             |
| Tan-<br>gents | 60'      | 50'     | 40'     | 30'     | 20'     | 10'     | 0'      | Degrees        |
| COTANGENTS    |          |         |         |         |         |         |         |                |



| De-<br>grees | COTANGENTS |           |           |           |          |          |          | Tangents |
|--------------|------------|-----------|-----------|-----------|----------|----------|----------|----------|
|              | 0'         | 10'       | 20'       | 30'       | 40'      | 50'      | 60'      |          |
| 0            | ∞          | 343.77371 | 171.88540 | 114.58865 | 85.93979 | 68.75009 | 57.28996 | 89       |
| 1            | 57.28996   | 49.10388  | 42.96408  | 38.18846  | 34.36777 | 31.24158 | 28.63625 | 88       |
| 2            | 28.63625   | 26.43160  | 24.54176  | 22.90377  | 21.47040 | 20.20555 | 19.08114 | 87       |
| 3            | 19.08114   | 18.07498  | 17.16934  | 16.34986  | 15.60478 | 14.92442 | 14.30067 | 86       |
| 4            | 14.30067   | 13.72674  | 13.19688  | 12.70621  | 12.25051 | 11.82617 | 11.43005 | 85       |
| 5            | 11.43005   | 11.05943  | 10.71191  | 10.38540  | 10.07803 | 9.78817  | 9.51436  | 84       |
| 6            | 9.51436    | 9.25530   | 9.00983   | 8.77689   | 8.55555  | 8.34496  | 8.14435  | 83       |
| 7            | 8.14435    | 7.95302   | 7.77035   | 7.59575   | 7.42871  | 7.26873  | 7.11537  | 82       |
| 8            | 7.11537    | 6.96823   | 6.82694   | 6.69116   | 6.56055  | 6.43484  | 6.31375  | 81       |
| 9            | 6.31375    | 6.19703   | 6.08444   | 5.97576   | 5.87080  | 5.76937  | 5.67128  | 80       |
| 10           | 5.67128    | 5.57638   | 5.48451   | 5.39552   | 5.30928  | 5.22566  | 5.14455  | 79       |
| 11           | 5.14455    | 5.06584   | 4.98940   | 4.91516   | 4.84300  | 4.77286  | 4.70463  | 78       |
| 12           | 4.70463    | 4.63825   | 4.57363   | 4.51071   | 4.44942  | 4.38969  | 4.33148  | 77       |
| 13           | 4.33148    | 4.27471   | 4.21933   | 4.16530   | 4.11256  | 4.06107  | 4.01078  | 76       |
| 14           | 4.01078    | 3.96165   | 3.91364   | 3.86671   | 3.82083  | 3.77595  | 3.73205  | 75       |
| 15           | 3.73205    | 3.68909   | 3.64705   | 3.60588   | 3.56557  | 3.52609  | 3.48741  | 74       |
| 16           | 3.48741    | 3.44951   | 3.41236   | 3.37594   | 3.34023  | 3.30521  | 3.27085  | 73       |
| 17           | 3.27085    | 3.23714   | 3.20406   | 3.17159   | 3.13972  | 3.10842  | 3.07768  | 72       |
| 18           | 3.07768    | 3.04749   | 3.01783   | 2.98869   | 2.96004  | 2.93189  | 2.90421  | 71       |
| 19           | 2.90421    | 2.87700   | 2.85023   | 2.82391   | 2.79802  | 2.77254  | 2.74748  | 70       |
| 20           | 2.74748    | 2.72281   | 2.69853   | 2.67462   | 2.65109  | 2.62791  | 2.60509  | 69       |
| 21           | 2.60509    | 2.58261   | 2.56046   | 2.53865   | 2.51715  | 2.49597  | 2.47509  | 68       |
| 22           | 2.47509    | 2.45451   | 2.43422   | 2.41421   | 2.39449  | 2.37504  | 2.35585  | 67       |
| 23           | 2.35585    | 2.33693   | 2.31826   | 2.29984   | 2.28167  | 2.26374  | 2.24604  | 66       |
| 24           | 2.24604    | 2.22857   | 2.21132   | 2.19430   | 2.17749  | 2.16090  | 2.14451  | 65       |
| 25           | 2.14451    | 2.12832   | 2.11233   | 2.09654   | 2.08094  | 2.06553  | 2.05030  | 64       |
| 26           | 2.05030    | 2.03526   | 2.02039   | 2.00569   | 1.99116  | 1.97680  | 1.96261  | 63       |
| 27           | 1.96261    | 1.94858   | 1.93470   | 1.92098   | 1.90741  | 1.89400  | 1.88073  | 62       |
| 28           | 1.88073    | 1.86760   | 1.85462   | 1.84177   | 1.82907  | 1.81649  | 1.80405  | 61       |
| 29           | 1.80405    | 1.79174   | 1.77955   | 1.76749   | 1.75556  | 1.74375  | 1.73205  | 60       |
| 30           | 1.73205    | 1.72047   | 1.70901   | 1.69766   | 1.68643  | 1.67530  | 1.66428  | 59       |
| 31           | 1.66428    | 1.65337   | 1.64256   | 1.63185   | 1.62125  | 1.61074  | 1.60033  | 58       |
| 32           | 1.60033    | 1.59002   | 1.57981   | 1.56969   | 1.55966  | 1.54972  | 1.53987  | 57       |
| 33           | 1.53987    | 1.53010   | 1.52043   | 1.51084   | 1.50133  | 1.49190  | 1.48256  | 56       |
| 34           | 1.48256    | 1.47330   | 1.46411   | 1.45501   | 1.44598  | 1.43703  | 1.42815  | 55       |
| 35           | 1.42815    | 1.41934   | 1.41061   | 1.40195   | 1.39336  | 1.38484  | 1.37638  | 54       |
| 36           | 1.37638    | 1.36800   | 1.35968   | 1.35143   | 1.34323  | 1.33511  | 1.32704  | 53       |
| 37           | 1.32704    | 1.31904   | 1.31110   | 1.30323   | 1.29541  | 1.28764  | 1.27994  | 52       |
| 38           | 1.27994    | 1.27230   | 1.2647    |           |          |          |          |          |



# PROBLEMS

---

## SECTION I

### INTRODUCTORY

The problems given hereafter are intended to furnish an adequate basis for any course in mechanical drawing in which the primary purpose is to instruct the student how to prepare pictorial and working drawings with speed, accuracy, and clearness of detail.

It is essential, of course, that the prospective draftsman first acquire a fair degree of mastery of the art of lettering. He must also learn how to use the drafting tools skilfully and accurately. To this end the problems in Sections II, III and IV have been provided, exemplifying the fundamental principles of lettering, of title design and of geometrical construction. A few more or less intricate exercises have been included in Section IV to give added practice in the use of instruments, although in the authors' own courses skill in the use of instruments is taught and acquired by the students almost wholly in connection with the daily drafting room work in orthographic and other forms of projection. In the same way, finesse in the technique of lettering is consciously acquired throughout the course by means of short weekly drills in "composition" and careful dimensioning, title work, and note or legend lettering on all drawings turned in by the student.

In Section III, only enough problems relating to title making are included to furnish a basis for more extended work in this field at the option of those in charge of drawing courses, and to suggest the materials to be included in typical cases.

The drawings presented cannot be considered as final standards in arrangement and technique for the student to copy. Many dimensions have, by necessity, been crowded into small areas and placed in illogical positions. In some instances dimensions and views are given which would not be put on a shop drawing at all; in other cases they are omitted altogether and the design left to the judgment of the draftsman.

It is assumed that most drafting rooms are equipped with models of machines and parts of machines, from which supplementary problems in scaling, sketching and drawing complete assemblies and details may be assigned the student from time to time. Any list of problems must needs be supplemented from models and specifications of local interest and bearing.

Variation may be introduced by a choice of scales differing from those specified in individual problems. The scales indicated have been fixed upon the basis of a 12"  $\times$  18" sheet with standard borders, and most solutions will be found to fit nicely within half and quarter subdivisions of this sheet.

## SECTION II

### LETTERING

Skill in lettering can only be achieved and retained by thoughtful practice. The eye must be accustomed to the true shapes of the letters before the hand can be made to reproduce them correctly.

The student should always have before him a perfect example of the element or letter he is to duplicate and he should criticize his product through comparison with the standard. It is intended that in performing any of the following exercises, the student should stop after each two or three letters and compare his results with the examples shown in the figures. The strokes shown in Figs. 1 to 17 inclusive are the fundamental ones in engineering lettering.

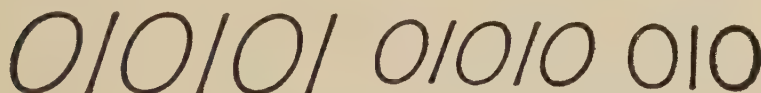


FIG. 2.



FIG. 3.

1. Rule sets of two guide lines  $\frac{3}{4}$ " apart with  $\frac{5}{16}$ " intervals between each set, and make an alternate series of smooth ovals and straight strokes, as shown in Fig. 1. Use several strokes of the pen on each element. Either the slant or the vertical style may be used.

2. Same as 1, using guide line spacing of  $\frac{1}{2}$ " and interval spacing of  $\frac{1}{4}$ ".  
Fig. 2.

3. Same as 1, using guide line spacing of  $\frac{3}{8}$ " and interval spacing of  $\frac{3}{16}$ ".  
Fig. 3.



FIG. 4.



FIG. 5.

4. Same as 1, using guide line spacing of  $\frac{1}{4}$ " and interval spacing of  $\frac{3}{16}$ ".  
Fig. 4. Use one stroke of the pen on each element.

5. Same as 1, using guide line spacing of  $\frac{5}{16}$ " and interval spacing of  $\frac{5}{32}$ ".  
Use one stroke of the pen on each element. Fig. 5.

6. Lay out an approximately 6"  $\times$  9" space on the drawing paper and, using a combination of the spacings shown in Figs. 1 to 5 inclusive, rule a series of guide lines beginning with two lines of the largest size and spacing

on down to the smaller sizes so that the sheet is filled. Use appropriately graded interval spacings — one-third to two-thirds the height of the letters. Practice the straight and oval strokes, first forming them with the pencil and then inking with several repetitive strokes of the pen on the larger sizes and only one stroke on the smaller sizes.

7. Rule several sets of three guide lines across a chosen space on the sheet with heights as shown in Fig. 6, and practice the letters: *illttccceeooss aaabbbdddpqq*. Slant or vertical style.

*illttccceeooss aaabbbdddpqq*

*illttccceeooss aaabbbdddpqq*

FIG. 6.

FIG. 7.

8. Same as 7, letters: *a b d p q*. Slant or vertical style. Fig. 7.

9. Same as 7, letters: *h n m r u*. Slant or vertical style. Fig. 8.

10. Same as 7, letters: *f g j y*. Slant or vertical style. Fig. 9.

11. Same as 7, letters: *k v w x z*. Slant or vertical style. Fig. 10.

*hhnnmmrruu fffggggjjjyyyyyy*

*hhnnmmrruu fffggggjjjyyyyyy*

FIG. 8.

FIG. 9.

*kkvvwwxxzz& 1234567890*

*kkvvwwxxzz& 1234567890*

FIG. 10.

FIG. 11

12. Rule several sets of two guide lines  $\frac{3}{16}$ " apart across a chosen space on the sheet with appropriate interval spacings between each set, and practice the numerals as shown in Fig. 11. Slant or vertical style.

*AAVVWWYY EEFFHHIILLTT*

*AAVVWWYY EEFFHHIILLTT*

FIG. 12.

FIG. 13.

*CCGGOOQQ MMNNZZKKXX*

*CCGGOOQQ MMNNZZKKXX*

FIG. 14.

FIG. 15.

**13-17.** Same as **12**, using the capital letters shown in Figs. 12 to 16, respectively.

*JJJSSSUUU abcdefghijklmno*

*JJJSSSUUU pqrstuvwxyyz&*

FIG. 16.

FIG. 17.

**18.** Rule guide lines and practice the letters of the alphabet in the order of their occurrence in it as shown in Fig. 17. Repeat until the proper skill has been acquired. Use slant or vertical letters.

**19.** Rule a series of  $\frac{3}{16}$ " guide lines over a selected area on the sheet, and letter the lines of composition as shown in Fig. 18. Use slant or vertical letters.

*Combining letters into words and words into sentences is called: "composition in freehand lettering"*

FIG. 18.

**20-25.** Rule a series of  $\frac{3}{16}$ " guide lines as in **Prob. 19** and print assigned paragraph. Use slant or vertical letters.

1. In order that a piece of composition may look well, it must have uniformity in slope, weight, size and spacing of the letters and words.

2. Control of the hand in lettering is best accomplished through short daily drills of from ten to twenty minutes' duration. The work should be deliberately and critically done.

3. The pen should be suited to the size and character of the work being done. A ball-point pen can hardly be used for fine letters; a fine-point pen should not be used for heavy work.

4. Keep the points of the pen free from dried ink, and clean thoroughly at the end of each piece of work. Fill the pen by means of the quill in the stopper of the ink bottle instead of dipping it in the bottle itself.

5. Triangles and T-square should be kept clean and free from dust and soot to prevent the drawing paper and tracing cloth from becoming soiled and unfit to work upon. Perspiration from the hands soon injures the surface qualities of the tracing cloth.

6. Plan the location of all the views of a drawing before beginning any. Reserve space for the title the very first thing. Allow generous space for dimensions and notes. Place these, as far as possible, between views.

7. Omit no dimension that may be needed for clearness, but do not repeat unnecessarily. Always give the overall dimension, and place it outside the detail dimensions. Do not hesitate to give explanatory notes.

## SECTION III

### TITLES

A drawing title should contain the following information: the name of the object drawn; the name and location of the person or firm for whom it is to be made; the name and location of the person or firm making the drawing; the names of the designer and draftsman; the scale, date, sheet numbers, and serial or contract number. The following problems are typical of those likely to arise in any drafting office.

**26.** Prepare a standard title to be placed on all drawings made in an architect's office on  $18'' \times 24''$  drawing sheets. Leave blank spaces for the name of the structure to be drawn and the name and address of the person or firm for whom work may be done. Include fictitious name of architect's office, address, date, and names of persons doing the design and drafting, etc. Before starting the final layout, submit a pencil sketch to the instructor, showing the prominence of each line of the title. Use vertical Roman letters and enclosing borders.

**27.** Design a standard title for the Brown Manufacturing Company, which is located at Lansing, Michigan, and makes bodies for various kinds of trucks and automobiles. Provide for sheet numbers, names of designer, draftsman, checker and tracer, scale, date, order numbers, and revision records. Assume name of firm for whom bodies are made. Drawing sheet used is  $24'' \times 36''$ . Use vertical Gothic letters with enclosing borders. Submit preliminary sketch to instructor before final layout is begun.

**28.** Design a title for a Topographical Map of the Taylor Lumber Company properties at Duluth, Minnesota. Include name of surveyor and date. The drawing sheet is  $18'' \times 24''$ . No enclosing borders for the title. Since there is to be only one map, there will be no sheet or serial number. Scale should be represented graphically. Use modern Roman letters. Submit preliminary sketch to instructor for approval before beginning final layout on drawing sheet.

**29.** Design a standard title suitable to the drawing sheets and problems in the course of which this work is a part. The name of the department, the school and its location are essentials in the title. Leave proper space for names of objects to be drawn. Gothic letters and enclosing borders will probably be suitable to most conditions. Titles varying in size from  $1'' \times 2''$  up to  $3'' \times 5''$  are used on ordinary drawings.



## SECTION IV

### USE OF INSTRUMENTS AND GEOMETRICAL CONSTRUCTIONS

In learning how to use and care for the drafting tools, no better preliminary practice can be had than that of constructing simple geometrical figures or combinations of such figures where accuracy in location of centers and determination of corners and points of tangency combines with skill in manipulation of the instruments to produce a good-looking result.

The methods of construction in the first twenty-four problems following are self-explanatory, while the next thirty-three require references to the Appendix for definitions and methods of construction. In most cases the full scale should be used unless other directions are given in assignment. Draw all figures in pencil, check, and then ink. Show all constructions in light pencil lines.

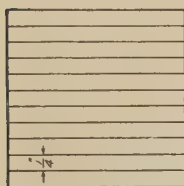


FIG. 19.



FIG. 20.

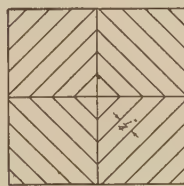


FIG. 21.

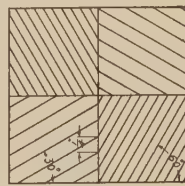


FIG. 22.

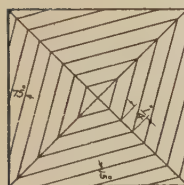


FIG. 23.

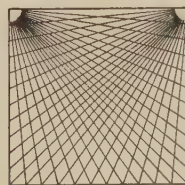


FIG. 24.

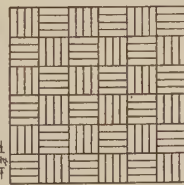


FIG. 25.

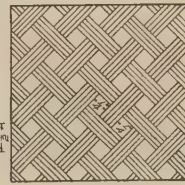


FIG. 26.

**30-53.** Divide the drawing sheet into equal spaces about 3 inches square. Reproduce the exercises assigned from Figs. 19-42 inclusive. Place constructions centrally in the squares. Draw in pencil, then ink.

**54.** Draw a circle of  $1''$  radius tangent to the center of a  $2\frac{3}{4}''$  line.

**55.** Draw a line  $2\frac{1}{2}''$  long and locate a point  $1\frac{1}{2}''$  from it at one end, then draw a circle of  $1\frac{1}{4}''$  radius through the point and tangent to the line.

**56.** Draw a circle of  $\frac{3}{4}''$  radius and select any point upon it, then draw a circle of  $\frac{1}{8}''$  radius tangent to the first circle at the chosen point.



FIG. 27.



FIG. 28.

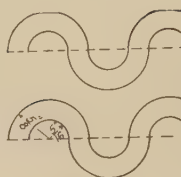


FIG. 29.

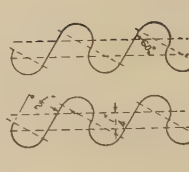


FIG. 30.



FIG. 31.

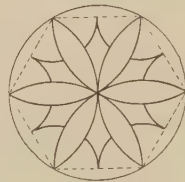


FIG. 32.

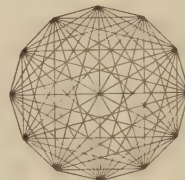


FIG. 33.

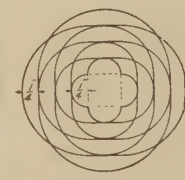


FIG. 34.

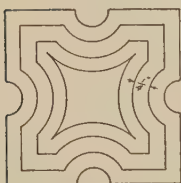


FIG. 35.

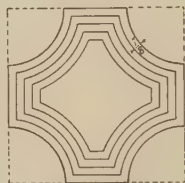


FIG. 36.

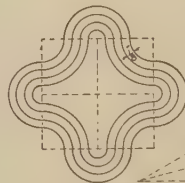


FIG. 37.

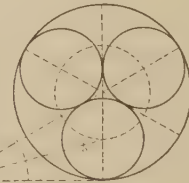


FIG. 38.

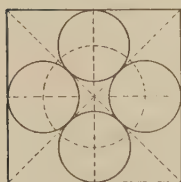


FIG. 39.

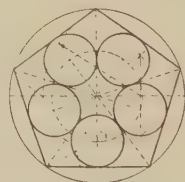


FIG. 40.

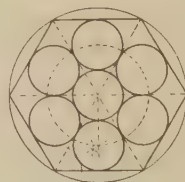


FIG. 41.

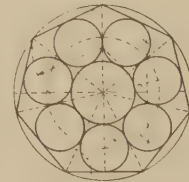


FIG. 42.

57. Draw two lines making an angle of  $30^\circ$  with each other and then draw a circle of  $\frac{1}{2}$ " radius tangent to them.

58. Draw two lines making an angle of  $45^\circ$  with each other and then draw a circle of  $\frac{3}{4}$ " radius tangent to them.

59. Draw two horizontal lines  $2\frac{1}{2}$ " long and  $2\frac{1}{2}$ " apart, and a circle of  $\frac{3}{4}$ " radius tangent to one line near its end. Draw a second circle of  $1\frac{1}{4}$ " radius tangent to the second line and to the circle.

60. Draw a line  $2\frac{1}{2}$ " long and a circle of  $\frac{3}{4}$ " radius with its center  $1\frac{1}{4}$ " from the line. Draw a second circle tangent to both line and circle so as to contain the circle.

61. Draw a circle of  $\frac{1}{2}$ " radius inside of an arc of  $2\frac{1}{2}$ " radius so that there is  $\frac{1}{2}$ " between them on their line of centers. Draw a circle of 1" radius tangent to the small circle and arc.

62. Draw two circles outside of each other, one of  $\frac{1}{2}$ " radius and the other of  $\frac{7}{8}$ " radius, so that there is  $\frac{1}{2}$ " between them on their line of centers. Draw a third circle of  $\frac{1}{2}$ " radius tangent to these two.

63. Draw two circles of  $\frac{1}{2}$ " radius each and  $\frac{1}{2}$ " apart on their line of centers. Draw a third circle tangent to the first two and so that it contains them.

64. Inscribe a circle in an equilateral triangle of  $2\frac{3}{4}$ " on the side.

65. Inscribe six circles of equal size in a circle of  $2\frac{7}{8}$ " diameter, so that the smaller circles are tangent to each other and to the large circle.

66. Construct an ellipse with its major axis  $2\frac{2}{3}$ " long and the minor axis 2" long, using an exact method.

67. Construct the ellipse of **Prob. 66** and then construct a tangent to it at a point approximately one-third of the distance from the minor to the major axis measured on the arc of the ellipse.

68. Construct an ellipse of  $2\frac{3}{4}$ " major axis and  $1\frac{1}{2}$ " minor axis by the four-center approximate method.

69. The conjugate axes of an ellipse are  $2\frac{1}{2}$ " and  $1\frac{3}{4}$ " and make an angle of  $75^\circ$  with each other. Construct the ellipse.

70. The major and minor axes of an ellipse are  $2\frac{3}{4}$ " and  $1\frac{1}{4}$ ". Construct the ellipse by the twelve-center approximate method.

71. Construct a parabola when the distance from the focus to the latus rectum (directrix) is  $\frac{3}{4}$ ".

72. Draw the parabola of **Prob. 71** and construct a tangent to it at a point  $\frac{3}{4}$ " from the latus rectum.

73. Construct a parabola in a rectangle  $1\frac{1}{2}$ " by 3", by the approximate method.

74. Construct an hyperbola with the distance between foci 1" and the distance between the two branches of the curves on the line joining the foci  $\frac{3}{4}$ ".

75. Construct the hyperbola of **Prob. 74** and draw a tangent to it at any point on the curve.

76. Draw an hyperbola in an enclosing rectangle  $1\frac{1}{2}$ " by 3", with the branches of the curves 1" apart. Use approximate method.

77. Construct a cycloid with a rolling circle  $1\frac{1}{2}$ " in diameter. (Space required, approximately  $3'' \times 6''$ .)

78. Construct a hypocycloid on a circle of 6" radius with a rolling circle of 1" in radius. (Space required, approximately  $3'' \times 6''$ .)

79. Construct an epicycloid with the same specifications given for **Prob. 78**.

80. Construct an involute of a circle 1" in diameter.

81. Construct a spiral of Archimedes, using a radius of curvature increment of  $\frac{1}{4}$ " per  $30^\circ$  of rotation.

82. Draw a segment of any irregular curve and construct a tangent to it by the secant method.

## SECTION V

### ORTHOGRAPHIC PROJECTION

The problems given in this section are intended to exemplify the different phases of shape description of objects by means of orthographic projections, and to represent varying degrees of difficulty encountered in objects usually dealt with in industrial or engineering practice, as well as to demonstrate how these difficulties are overcome on the drawings. The scale indicated may be changed by assignment to fit the conditions of paper and drawing equipment required of the student. It is suggested that dimensions be omitted on the student's drawings until the application of the theory is well understood, but they may be added by assignment.

#### PROBLEMS IN TWO- AND THREE-VIEW ORTHOGRAPHIC PROJECTION

**83-94.** Make a two-view orthographic projection of an assigned object from Figs. 49, 52, 53, 57, 77, 79, 80, 82, 83, 84, 85, 86. Scale  $1'' = 1''$ .

**95-99.** Make a two-view orthographic projection of an assigned object from Figs. 50, 51, 55, 74, 75. Scale  $\frac{3}{4}'' = 1''$ .

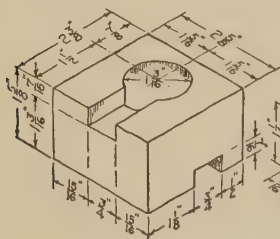


FIG. 43.

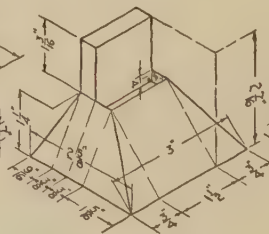


FIG. 44.

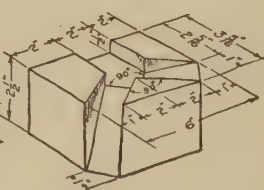


FIG. 45.

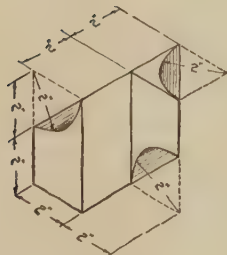


FIG. 46.

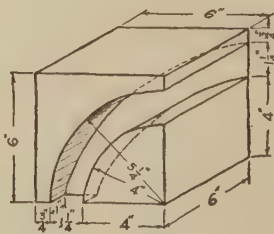


FIG. 47.

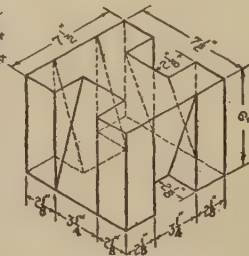


FIG. 48.

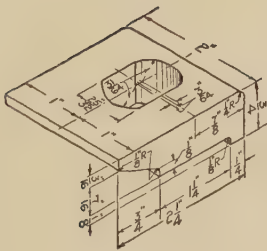


FIG. 49. Rail clip.

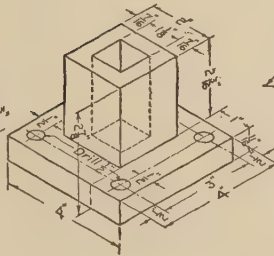


FIG. 50. Pedestal.

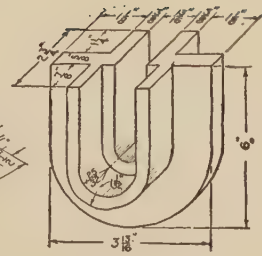


FIG. 51. U-Block.

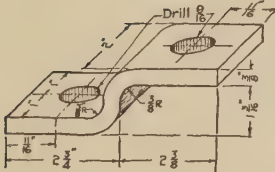


FIG. 52. Clip.

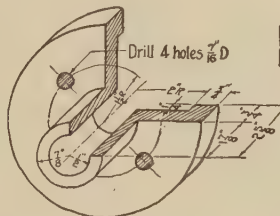


FIG. 53. End plate.

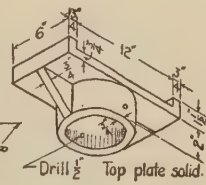


FIG. 54. Post cap.

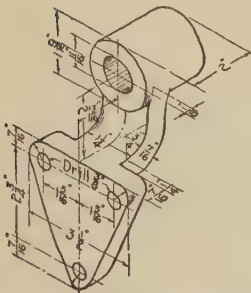


FIG. 55. Bearing bracket.

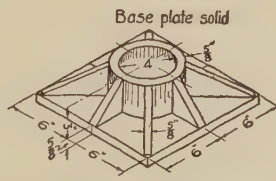


FIG. 56. Column base.

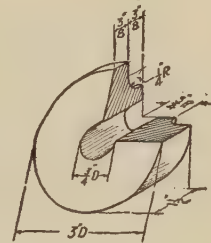


FIG. 57. Bevel washer.

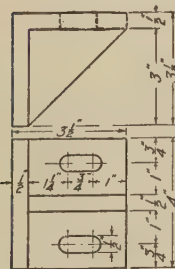


FIG. 58. Bracket.

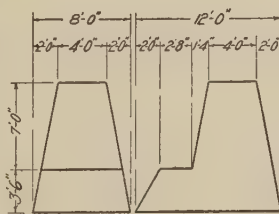


FIG. 59. Abutment.

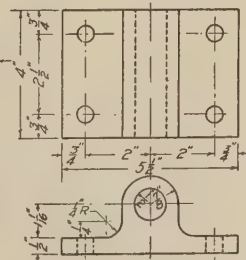


FIG. 60. Pillow block.





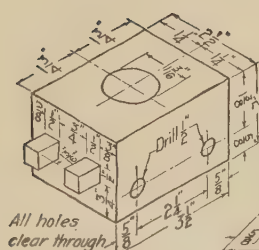


FIG. 73.

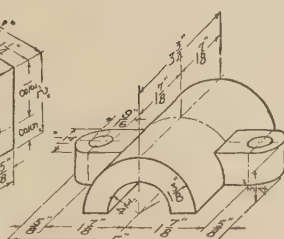


FIG. 74. Bearing cap.

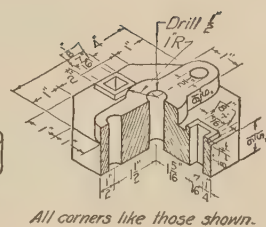


FIG. 75.

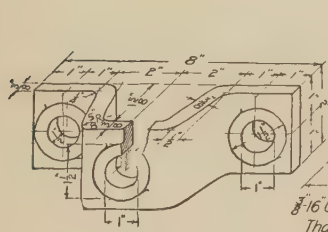


FIG. 76. Pivot block.

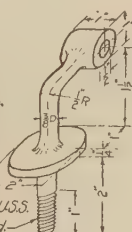


FIG. 77. Screw hinge.

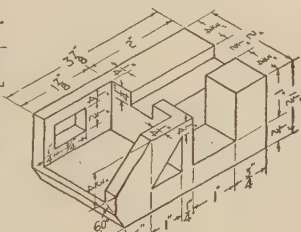


FIG. 78.

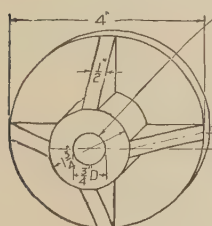


FIG. 79. Washer.

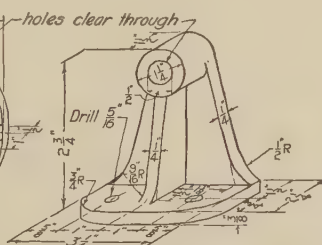


FIG. 80. Bearing post.

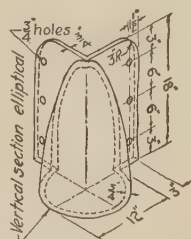


FIG. 81. Wheel guard.

100-101. Make a two-view orthographic projection of an assigned object from Figs. 47 and 76. Scale  $\frac{1}{2}'' = 1''$ .

102-104. Make a two-view orthographic projection of an assigned object from Figs. 54, 56, 81. Scale  $3'' = 1' - 0''$ .

105-106. Make a three-view orthographic projection of an assigned object from Figs. 43 and 44. Scale  $1'' = 1''$ .

107-111. Make a three-view orthographic projection of an assigned object from Figs. 45, 46, 73, 78, 87. Scale  $\frac{3}{4}'' = 1''$ .

112. Make a three-view orthographic projection of the object shown in Fig. 48. Scale  $\frac{1}{2}'' = 1''$ .

113-121. Copy the views given and make a third view of an assigned object from Figs. 58, 60, 61, 62, 64, 67, 69, 71, 72. Scale  $\frac{3}{4}'' = 1''$ .



**140-145.** Figs. 88 to 93. Reproduce figure assigned. Find its intersection with a plane perpendicular to the H-plane and parallel to  $AB$  and  $\frac{1}{4}''$  from it. Project the intersection on to an auxiliary plane parallel to the cutting plane.

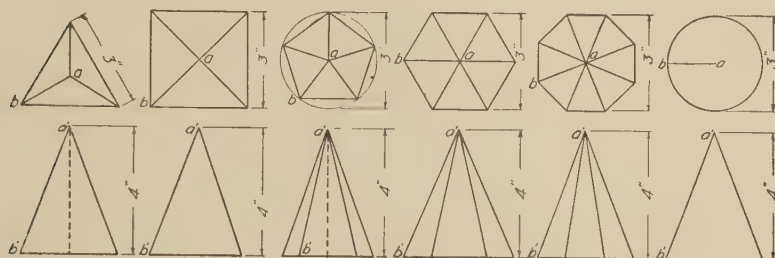


FIG. 88.      FIG. 89.      FIG. 90.      FIG. 91.      FIG. 92.      FIG. 93.

**146-151.** Figs. 88 to 93. Reproduce figure assigned. Find its intersection with a plane through the center point of the axis, perpendicular to the end or profile plane, and inclined  $45^\circ$  to both H- and V-planes. Project the intersection on to an auxiliary plane parallel to the cutting plane. Develop the surface of the frustum of the solid.

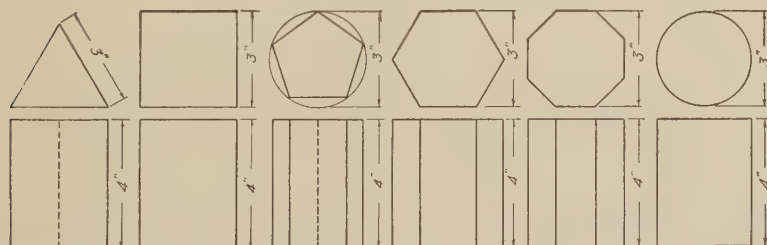


FIG. 94.      FIG. 95.      FIG. 96.      FIG. 97.      FIG. 98.      FIG. 99.

**152-157.** Figs. 94 to 99. Reproduce figure assigned. Find its intersection with a plane through the center point of the axis, perpendicular to the V-plane, and inclined  $30^\circ$  to the H-plane. Project the intersection on to an auxiliary plane parallel to the cutting plane.

**158-163.** Figs. 94 to 99. Reproduce figure assigned. Find its intersection with a plane through the center point of the axis, perpendicular to the profile or end plane, and inclined  $45^\circ$  to both the H- and V-planes.

**164.** Make a three-view orthographic drawing of the block shown in Fig. 100 and then draw two auxiliary views. Omit dimensions. Scale  $\frac{3}{4}'' = 1''$ .

**165.** Make a two-view orthographic drawing of the angle bearing pedestal shown in Fig. 101 and then show the one necessary auxiliary view. Omit dimensions. Scale  $\frac{3}{4}'' = 1''$ .

**166.** Make a two-view orthographic drawing of the post bracket shown in Fig. 102 and then show the one necessary auxiliary view. Omit dimensions. Scale  $3'' = 1' - 0''$ .





171. Make a three-view orthographic drawing of the bracket shown in Fig. 107 and then draw the one necessary auxiliary view. Omit dimensions. Scale  $\frac{3}{4}'' = 1''$ .

172. Copy the two-view orthographic drawing given in Fig. 108 and show the true shape and size of faces A, B, C, D, or E according to assignment. Omit dimensions. Scale  $\frac{3}{8}'' = 1' - 0''$ .

### TRANSVERSE SECTIONS

173. Make a two-view orthographic drawing of the post cap of Fig. 109, showing a full section in one view. Omit dimensions. Scale  $3'' = 1' - 0''$ .

174. Make a two-view orthographic drawing of the staff pedestal of Fig. 110, showing a half section in one view. Omit dimensions. Scale  $\frac{1}{2}'' = 1''$ .

175. Make a two-view orthographic drawing of the column pedestal of Fig. 111, showing a full section in one view. Omit dimensions. Scale  $3'' = 1' - 0''$ .

176. Make a two-view orthographic drawing of the sheave of Fig. 112, showing a half section in one view. Omit dimensions. Scale  $\frac{3}{4}'' = 1''$ .

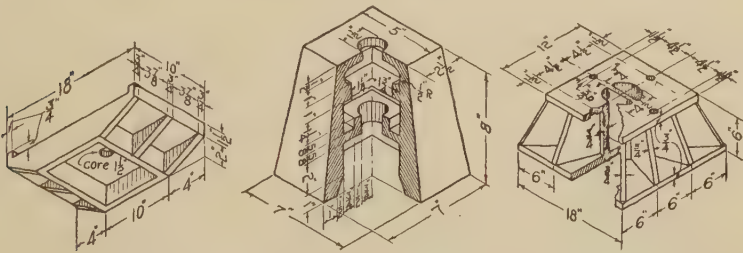


FIG. 109. Post cap. FIG. 110. Staff pedestal. FIG. 111. Column pedestal.

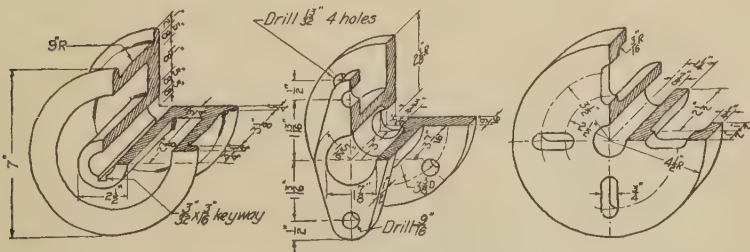


FIG. 112. Sheave. FIG. 113. Stuffing box. FIG. 114. Face-plate blank.

177. Make a two-view orthographic drawing of the body of the stuffing box of Fig. 113, showing a half section in one view. Omit dimensions. Scale  $\frac{3}{4}'' = 1''$ .

178. Make a two-view orthographic drawing of the face plate blank of Fig. 114, showing a half section in one view. Omit dimensions. Scale  $\frac{3}{4}'' = 1''$ .

179. Copy the two-view drawing of end of girder shown in Fig. 115, then make a full-sectioned third view on plane "AA" looking in direction indicated. Omit dimensions. Scale  $1'' = 6''$ .

180. Copy the two-view drawing of the truss block of Fig. 116 then make a full-sectioned end view. Omit dimensions. Scale  $\frac{1}{4}'' = 1''$ .

181. Copy the two-view drawing of the skew arch of Fig. 117, then show a full section on a plane perpendicular to the axis. Omit dimensions. Scale  $\frac{1}{4}'' = 1' - 0''$ .

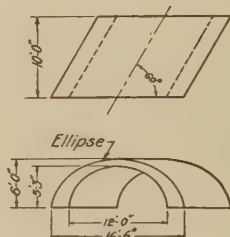
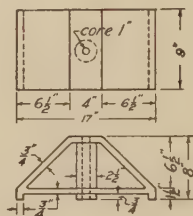
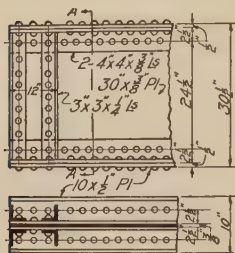


FIG. 115. Girder end.

FIG. 116. Truss block.

FIG. 117. Skew arch.

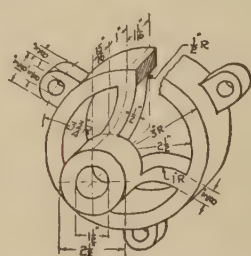
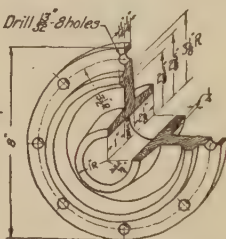
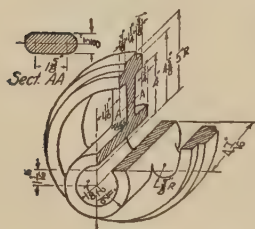


FIG. 118. Eccentric sheave.

FIG. 119. End plate.

FIG. 120. Offset bearing.

182. Make a two-view orthographic drawing of the eccentric sheave of Fig. 118, showing a half section in one view. Omit dimensions. Scale  $\frac{1}{2}'' = 1''$ .

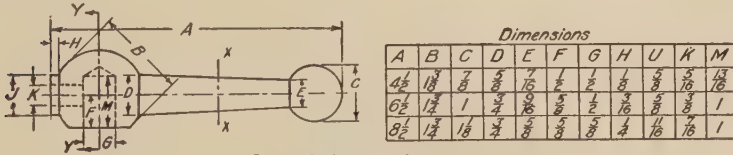
183. Make a two-view orthographic drawing of the end plate of Fig. 119, showing a half section in one view. Omit dimensions. Scale  $\frac{1}{2}'' = 1''$ .

184. Make a two-view orthographic drawing of the offset bearing of Fig. 120, showing a half section in one view. Omit dimensions. Scale  $\frac{1}{2}'' = 1''$ .

185-187. Make a two-view orthographic drawing of the clamping lever of Fig. 121, using dimensions from table according to length assigned. Show revolved sectioned view on plane "XX" and removed sectioned view on plane "YY." Select scale.

188. Make an interpolated sectioned view of desk arm of Fig. 71 on a plane approximately midway between the two ends. Scale  $1'' = 1''$ . Repeat for connecting rod of Fig. 226.

189. Make an interpolated sectioned view of socket wrench of Fig. 223 on a plane approximately midway between the two ends. Scale  $1'' = 1''$ . Repeat for crank of Fig. 234.



Two-ball clamping lever

FIG. 121. Clamping lever.

## SECTION VI

### FASTENERS

Use full scale on all problems of this section. Do not conventionalize threads unless so directed. Show two views in all cases. Length of all bolts and screws of specified threads,  $2\frac{1}{2}''$ .

190. Construct a helix of  $1\frac{1}{2}''$  diameter and  $2''$  pitch.
191. Draw a helical spring made of rectangular steel bar  $\frac{1}{8}'' \times \frac{1}{4}''$ . Inside diameter  $1\frac{1}{2}''$ , pitch  $\frac{3}{4}''$ .
192. Draw a helical spring made of round steel bar  $\frac{1}{2}''$  in diameter. Inside diameter  $2''$  and pitch  $1\frac{1}{2}''$ .
193. Draw an hexagonal-head U. S. S. bolt  $1''$  in diameter.
194. Same as 193, using square-head bolt.
195. Draw a No. 30 A. S. M. E. machine screw with an assigned head — round, flat, flat fillister, or oval fillister. Show threads conventionalized.
196. Draw a  $\frac{3}{4}''$  diameter cap screw with assigned head — hexagonal, square, flat, oval, or flat countersunk. Show threads conventionalized.
197. Draw a  $\frac{3}{4}''$  diameter A. S. M. E. round-head set screw.
198. Draw a headless set screw with assigned point — conical, cup, flat, etc.
199. Draw a stud bolt,  $4''$  long,  $1\frac{1}{2}''$  diameter, threaded  $1\frac{1}{2}''$  on each end.
200. Draw a single right-hand square thread,  $2''$  outside diameter, pitch  $\frac{1}{2}''$ .
201. Draw a single left-hand square thread,  $2''$  outside diameter, pitch  $\frac{1}{2}''$ .
202. Draw a double right-hand square thread,  $2\frac{1}{2}''$  outside diameter, pitch  $\frac{1}{2}''$ .
203. Draw a double left-hand square thread,  $2\frac{1}{2}''$  outside diameter, pitch  $\frac{1}{2}''$ .
204. Draw a single right-hand standard sharp V-thread,  $2\frac{1}{2}''$  diameter.
205. Draw a single left-hand standard sharp V-thread,  $2\frac{1}{2}''$  diameter.
206. Draw a nut in full section to fit the thread of **Prob. 205**.
207. Draw a double right-hand sharp V-thread,  $2''$  crest diameter, standard pitch.
208. Draw a double left-hand sharp V-thread,  $2''$  crest diameter, standard pitch.
209. Draw a triple right-hand V-thread,  $1\frac{1}{2}''$  crest diameter, standard pitch.
210. Draw a single right-hand Acme thread,  $1\frac{1}{2}''$  diameter, four and one-half threads per inch.
211. Draw a single left-hand Acme thread,  $1\frac{1}{2}''$  diameter, four and one-half threads per inch.

ELEMENTS OF THE ACME STANDARD THREAD

| Thds.<br>per<br>inch | Depth<br>of<br>thread | Width<br>of flat<br>at top<br>of<br>thread | Width<br>of flat<br>at root<br>of<br>thread | Threads<br>per<br>inch | Depth<br>of<br>thread | Width<br>of flat<br>at top<br>of<br>thread | Width<br>of flat<br>at root<br>of<br>thread |
|----------------------|-----------------------|--------------------------------------------|---------------------------------------------|------------------------|-----------------------|--------------------------------------------|---------------------------------------------|
| 1                    | 0.5100                | 0.3707                                     | 0.3655                                      | 5                      | 0.1100                | 0.0741                                     | 0.0689                                      |
| 1½                   | 0.3433                | 0.2471                                     | 0.2419                                      | 5½                     | 0.1009                | 0.0674                                     | 0.0622                                      |
| 2                    | 0.2600                | 0.1853                                     | 0.1801                                      | 6                      | 0.0933                | 0.0618                                     | 0.0566                                      |
| 2½                   | 0.2100                | 0.1483                                     | 0.1431                                      | 7                      | 0.0814                | 0.0530                                     | 0.0478                                      |
| 3                    | 0.1767                | 0.1236                                     | 0.1184                                      | 8                      | 0.0725                | 0.0463                                     | 0.0411                                      |
| 3½                   | 0.1529                | 0.1059                                     | 0.1007                                      | 9                      | 0.0656                | 0.0412                                     | 0.0360                                      |
| 4                    | 0.1350                | 0.0927                                     | 0.0875                                      | 10                     | 0.0600                | 0.0371                                     | 0.0319                                      |
| 4½                   | 0.1211                | 0.0824                                     | 0.0772                                      | 12                     | 0.0517                | 0.0309                                     | 0.0257                                      |

212. Construct a conical helix, base of cone 2" diameter, altitude 3½", pitch 1".

213. Draw a conical spring made of ¼" square steel bar. Base of cone 2½" diameter, altitude 4". Spring 2½" high, pitch ½".

214. Draw a 1¼" U. S. S. hexagonal-head bolt, 3½" long, with the nut turned on and shown in half section.

215. Make a section of a double-riveted single lap joint. Use ¼" steel plate and ½" button-head rivets.

216. Make a section of a double-riveted, single-plate, butt joint. All plates ⅜" thick. Rivets, ⅝" cone head.

217. Make a section of a double-riveted, double-plate, butt joint. Plates ⅜" thick. Rivets, ¾" round head.



## WORKING OR SHOP DRAWINGS

**Cornshaft Timing Gear (Intermediate)**

No. A-56 1 Reg'd C.I., F.A.O

7½ teeth blw punch marks  
4 Oil holes, Drill No. 30  
Oil grooves  
30 Teeth  
No. 4/10 Pitch-Cutter  
Pitch Dia. 3"  
Root Dia. 2.768"

Ream  
1.376"  
1.375"  
1.376"  
3.200"  
3.195"  
62°  
62°

16  
12  
8

Drill No. 3  
Top  $\frac{1}{4} \times 28$  S.A.E.  
Std.

Drill  $\frac{1}{2}$ "

1"

$\frac{3}{8}$ "

G.R. Steel - S.A.E. No 1020  
Timer Shaft Collar.

No. A-147, 2 Read FAO.

FIG. 124.

<sup>1</sup> Engine was designed and made in shop laboratories of the University of Illinois, and the drawings are included here by their permission.

The following abbreviations have been used on the drawings in addition to those given in the body of the text: S. A. E. — Society of Automotive Engineers; U. S. F. — United States Form; L. H. — Left Hand; F. A. O. — Finish All Over; G — Grind.

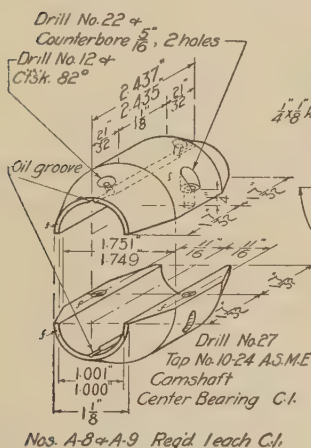


FIG. 125.

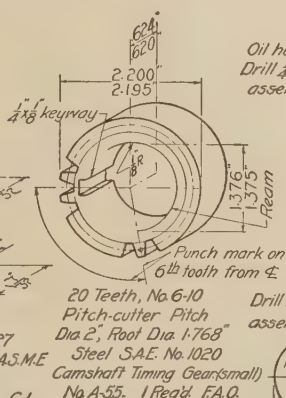


FIG. 126.

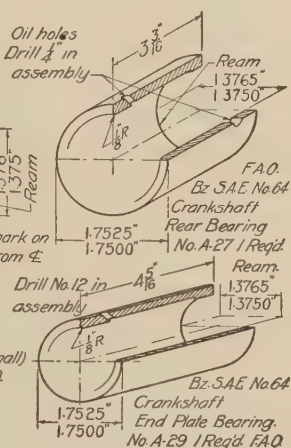


FIG. 127.

FIG. 128.

**218-227.** Make a two-view working drawing of an assigned object from Figs. 49, 52, 53, 77, 79, 80, 82, 83, 85, 86. Section where necessary. Scale  $1'' = 1'$ .

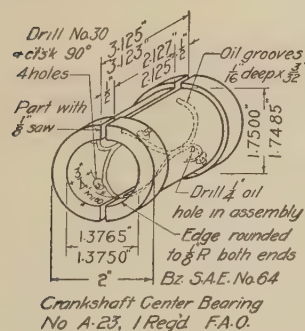


FIG. 129.

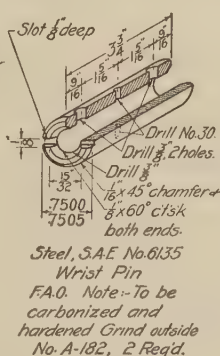


FIG. 130.

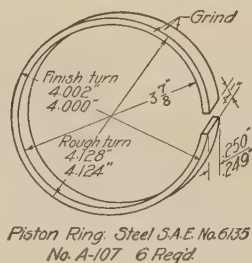


FIG. 131.

**228-245.** Make a two-view working drawing of an assigned gas engine part from Figs. 123, 124, 127, 128, 129, 131, 135, 142, 143, 151, 157, 162, 165, 166, 167, 170, 172, 175. Section where necessary. Scale  $1'' = 1''$ .

**246-253.** Make a two-view working drawing of an assigned gas engine part from Figs. 122, 138, 139, 140, 141, 144, 150, 156. Section where necessary. Scale  $1'' = 1''$ .

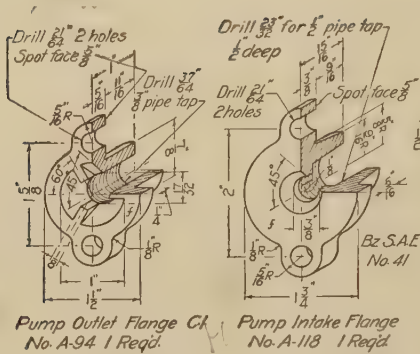


FIG. 132.

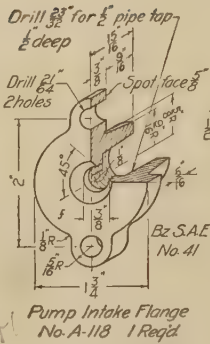


FIG. 133.

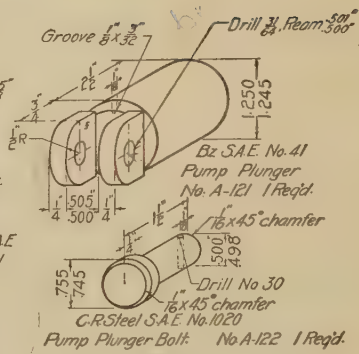


FIG. 134.

FIG. 135.

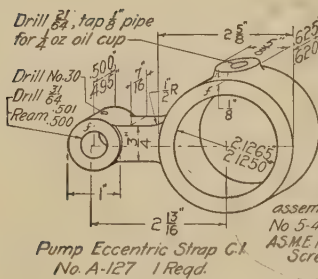


FIG. 136.

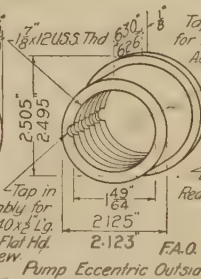


FIG. 137.

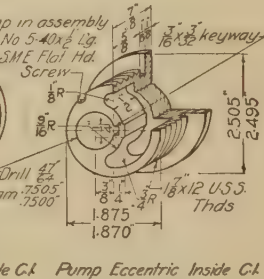


FIG. 138.

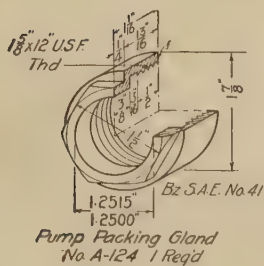


FIG. 139.

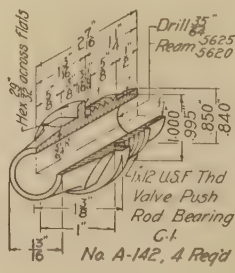


FIG. 140.

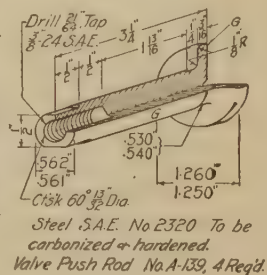


FIG. 141.

254-258. Make a two-view working drawing of an assigned object from Figs. 50, 51, 55, 74, 113. Section where necessary. Scale  $\frac{3}{4}$ " = 1".

259-261. Make a two-view working drawing of an assigned gas engine part from Figs. 136, 137, 154. Section where necessary. Scale  $\frac{3}{4}$ " = 1".

262-263. Make a two-view working drawing of an assigned gas engine part from Figs. 161 and 171. Scale  $\frac{1}{2}$ " = 1".

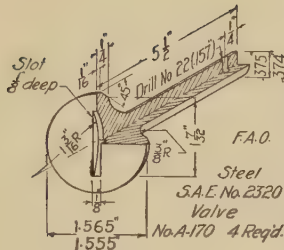


FIG. 142.



FIG. 143.

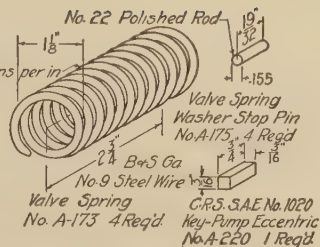


FIG. 144. FIG. 145.

FIG. 146.

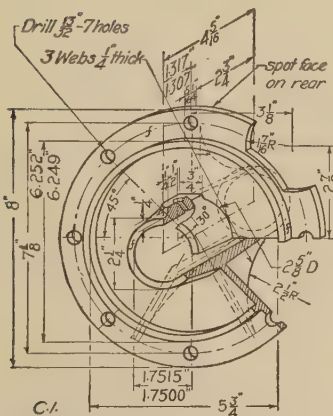


FIG. 147.

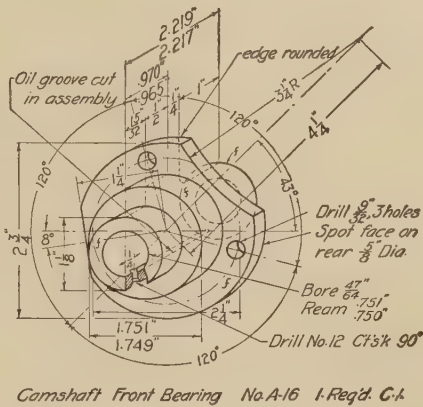


FIG. 148.

264-273. Make a two-view working drawing of an assigned object from Figs. 54, 56, 76, 102, 109, 112, 114, 118, 119, 120. Section where necessary. Scale, select.

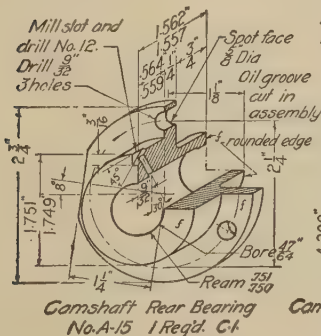


FIG. 149.

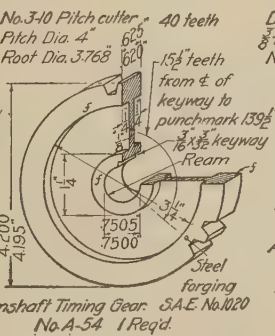


FIG. 150.

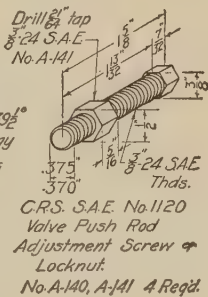


FIG. 151.







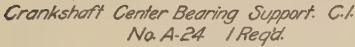
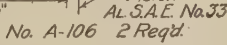
[illegible]

FIG. 157.



Drill 2 1/2" Spot face 1/16"

4 Recesses for screw head clearance.

This edge rounded to 3/8" R

Manifold Intake Elbow. C.I. No. A-63-1 Req'd.

FIG. 159.



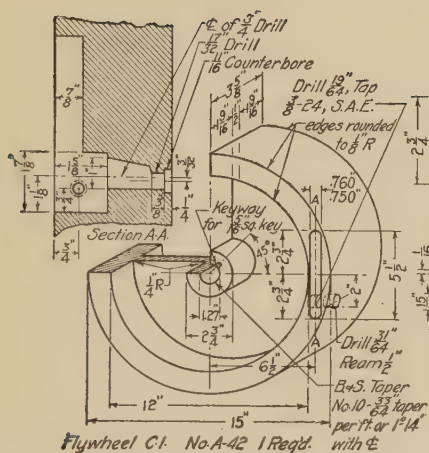


FIG. 169.

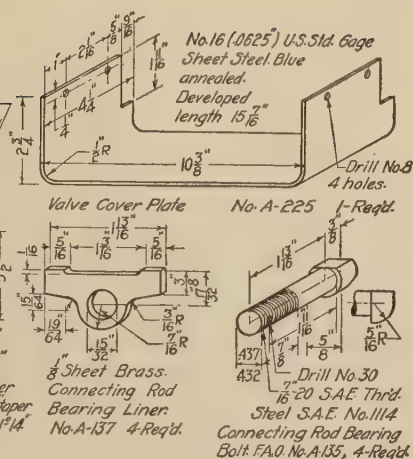


FIG. 171.

FIG. 172.

**306-309.** Make a three-view working drawing of an assigned gas engine part from Figs. 152, 155, 158, 159. Section where necessary. Scale, select.

**310.** Make a two-view working drawing of the camshaft of Fig. 160. Show a cam layout on full-size scale. Scale  $\frac{1}{2}'' = 1''$ .

**311.** Make a two-view working drawing of the handhole plate of Fig. 168. Scale  $\frac{1}{2}'' = 1''$ . Show a section through breather on full-size scale.

**312.** Make a two-view working drawing of the flywheel of Fig. 169. Scale  $\frac{1}{2}'' = 1''$ . Show a section through handle as indicated in the Fig.

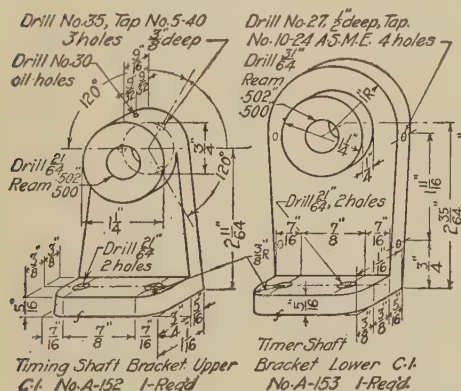


FIG. 173.

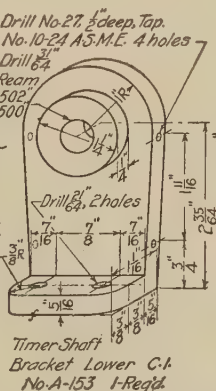


FIG. 174.

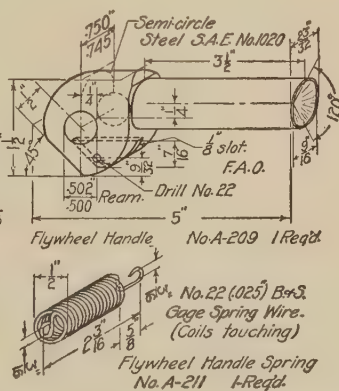


FIG. 176.

FIG. 175.

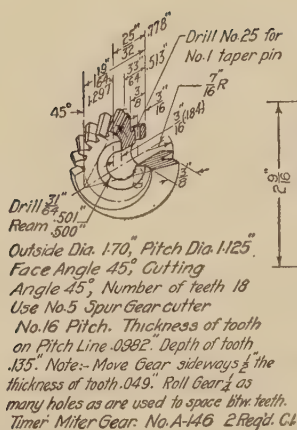


FIG. 177.

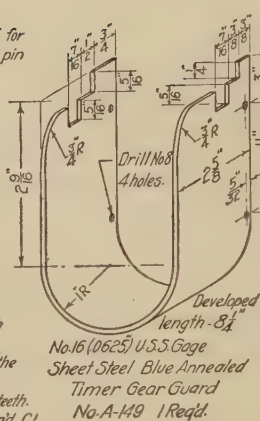


FIG. 178.

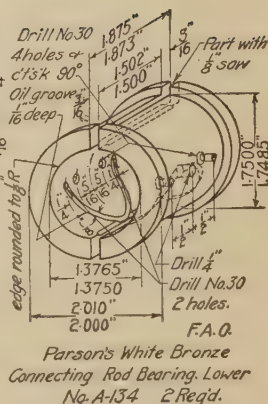


FIG. 179.

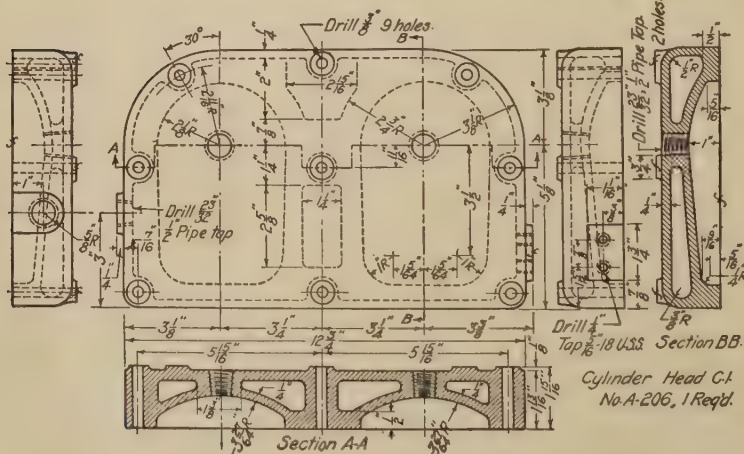


FIG. 180.

**313-318.** Copy an assigned working drawing of gas engine parts from Figs. 180, 181, 182, 183, 184, 185. Rearrange and allow more space for dimensions. Scale, select.

**319-321.** Make a working drawing of an assigned part of the drillblock and clamp of Fig. 186 — screw, clamp, and block. Scale, select.

**322-323.** Make a working drawing of an assigned part of the cutting head of Fig. 187 — locking bolt with nut and head with set screw. Scale, select.

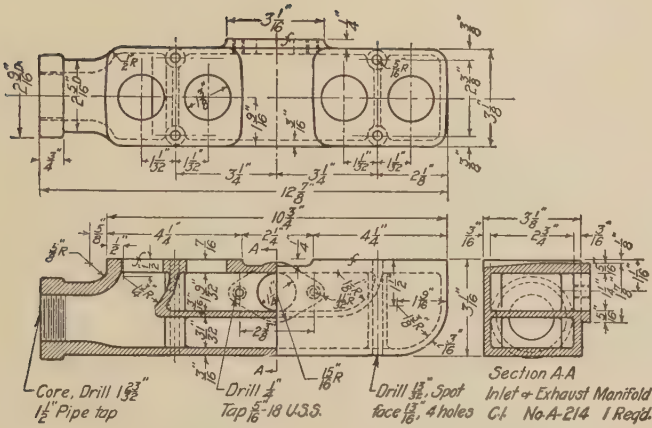


FIG. 181.

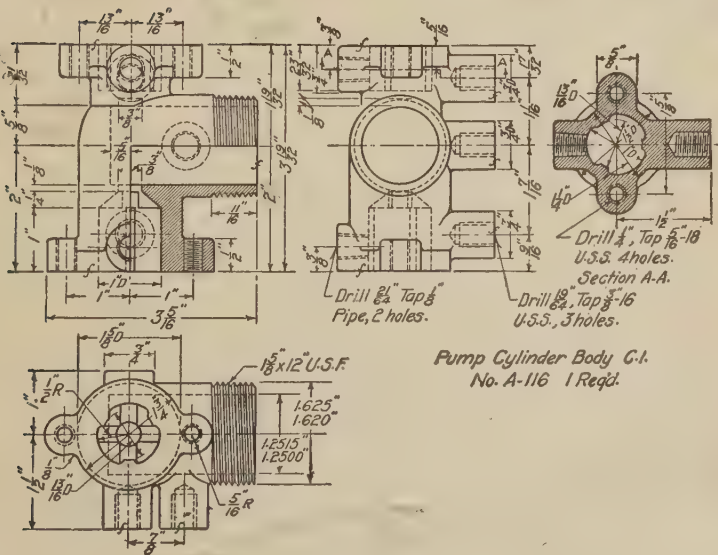
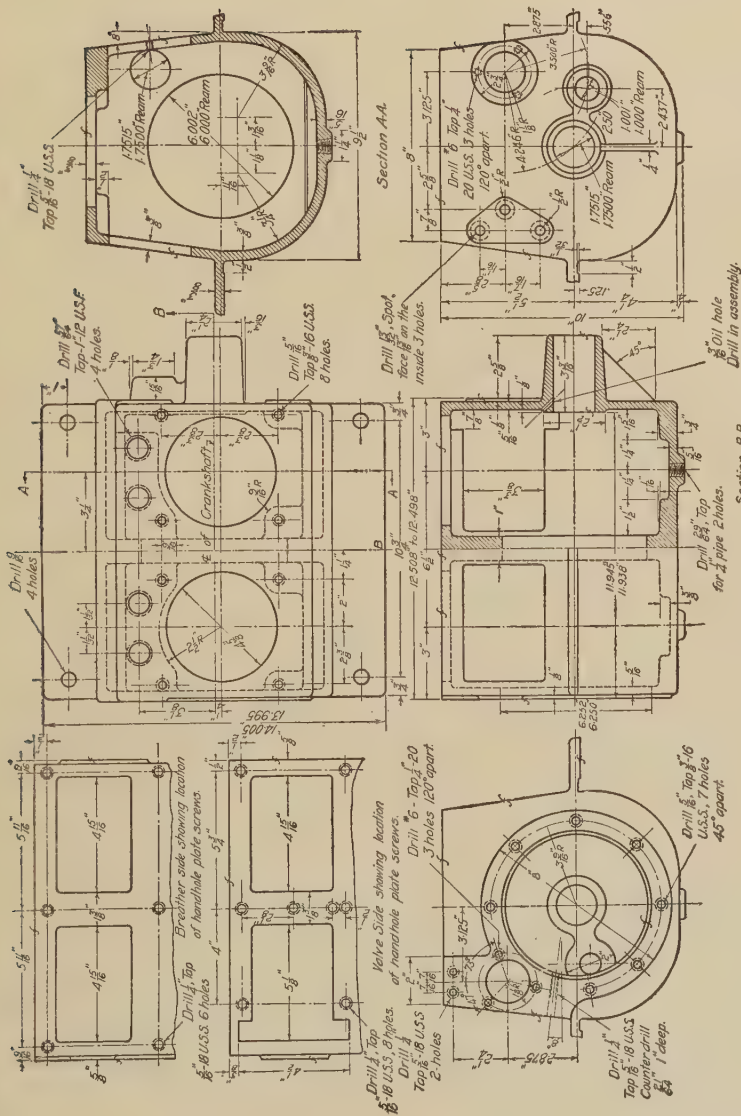


FIG. 182.

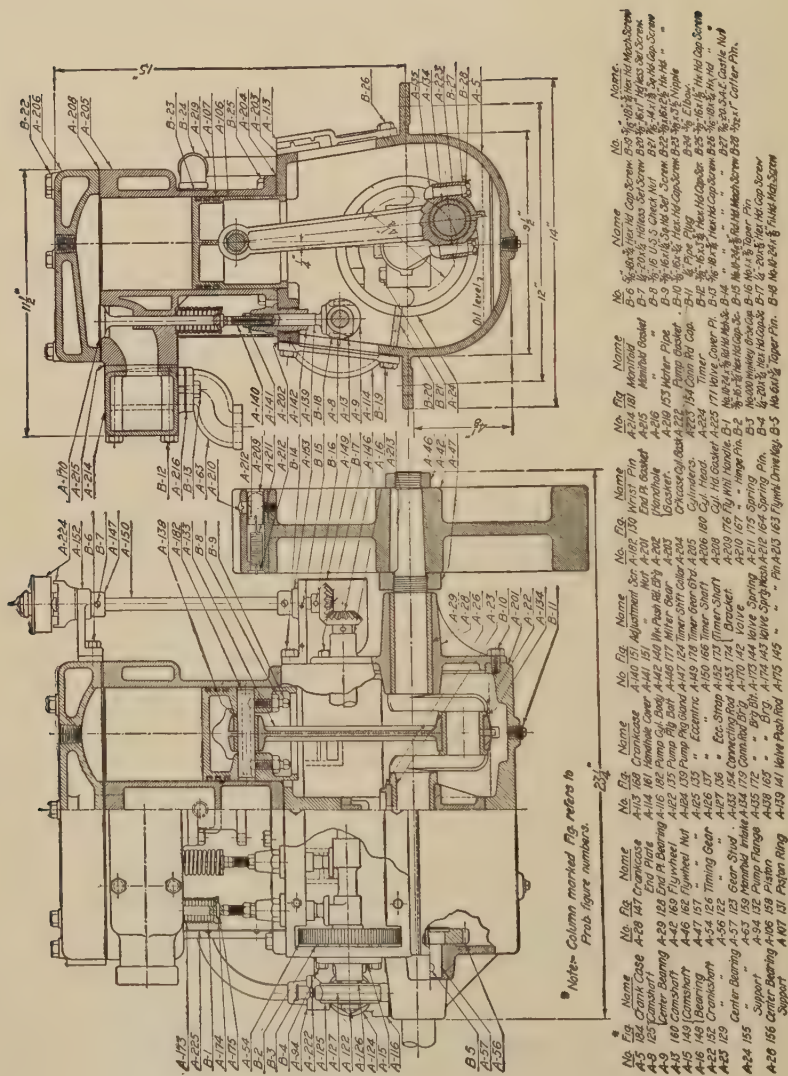






Crankcase Case C-1 No. A-5 Read.

FIG. 184.



377

**324-326.** Make a working drawing of an assigned part of the stuffing box of Fig. 188 — body, gland, and stud bolt with nut. Scale, select.

**327-329.** Make a working drawing of an assigned part of the double cone coupling of Fig. 189 — sleeves, conical bushing, and bolts with nuts. Scale, select.

**330-331.** Make a working drawing of an assigned part of the off-center coupler of Fig. 190 — flange and sliding block. Scale, select.

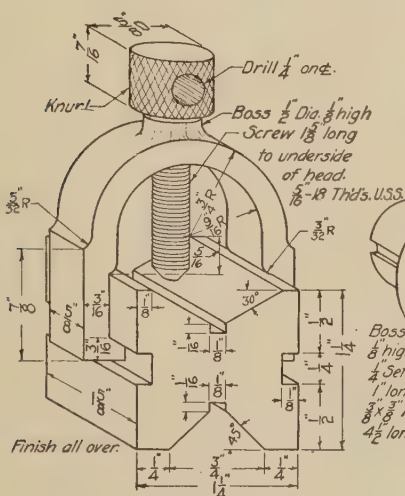


FIG. 186. Drill block.

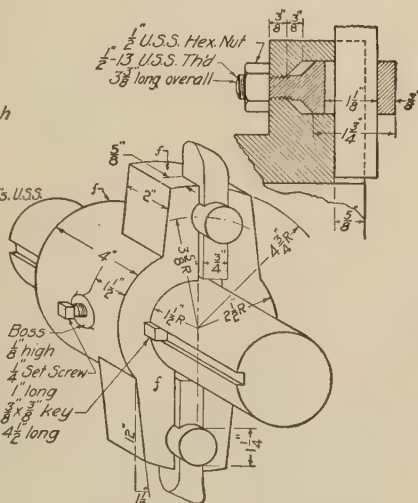


FIG. 187. Cutting head.

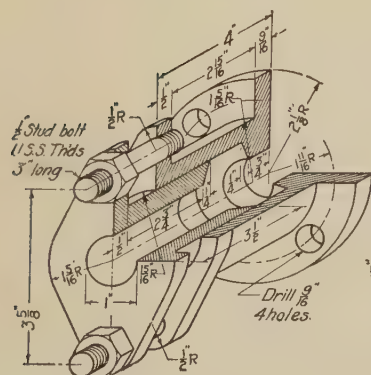


FIG. 188. Stuffing box.

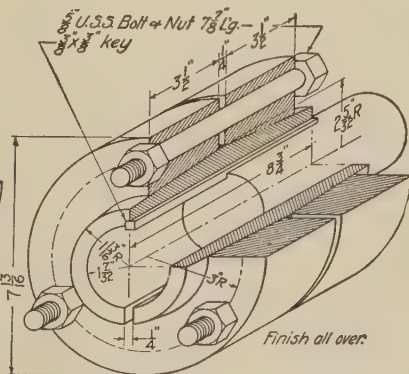


FIG. 189. Double cone coupling.

**332-335.** Make a working drawing of an assigned part of the tool-maker's clamp of Fig. 191 — base block, jaw, screw, and handle with ball. Scale, select.







**336-339.** Make a working drawing of an assigned part of the planer jack of Fig. 192 — base, ram, screw, and pin with nut. Scale, select.

**340-342.** Make a working drawing of an assigned part of the stuffing box of Fig. 193 — body, gland, and gland nut. Scale, select.

**343-345.** Make a working drawing of an assigned part of the ball universal joint of Fig. 194 — jaw, ball, and swivel pins with set screw. Scale, select.

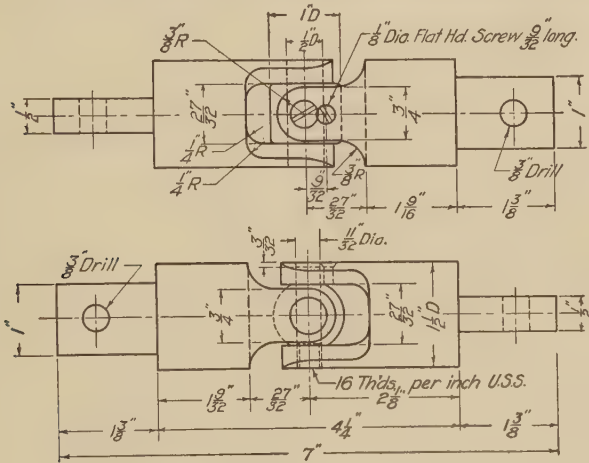


FIG. 194. Universal joint.

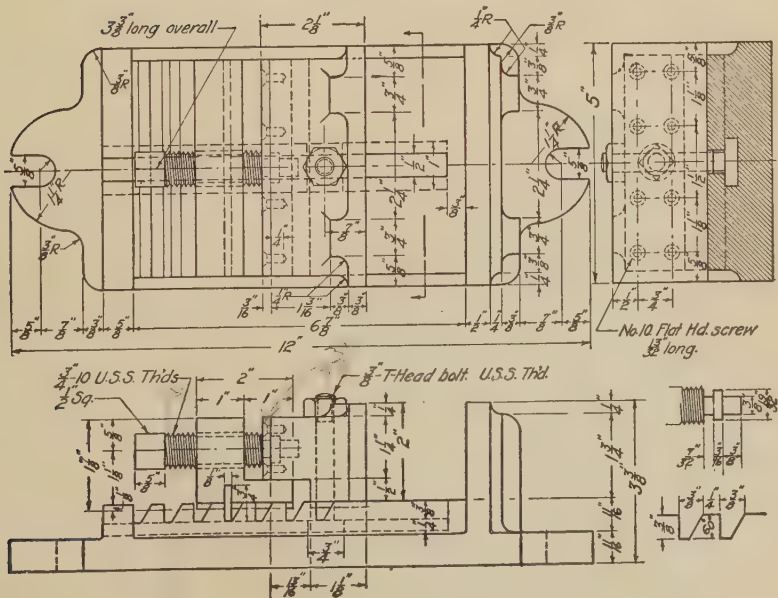


FIG. 195. Drill clamp.

**346-352.** Make a working drawing of an assigned part of the drill clamp of Fig. 195 — base, sliding head, stop block, screw, clamping plate, head plate with machine screws, and T-bolt with nut. Scale, select.

**353-357.** Make a working drawing of an assigned part of the boiler man-hole of Fig. 196 — frame, yoke, cover, handle with cap screws, and locking bolt with nut. Scale, select.

**358-365.** Make a working drawing of an assigned part of the globe valve of Fig. 197. Scale, select.

**366-373.** Make a working drawing of an assigned part of the shaft hanger of Fig. 198. Scale, select.

**374.** Make a two-view assembly drawing, consisting of parts A-139, A-140, A-141 and A-142, of two-cylinder gas engine. Full section. Scale  $2'' = 1''$ . See Fig. 185 for key to part numbers.

**375.** Make a two-view assembly drawing, consisting of parts A-15, A-16, A-54, A-8, A-9, A-13, of two-cylinder gas engine. Full section. Scale, select. See Fig. 185 for key to part numbers.

**376.** Make a two-view assembly drawing of gas engine pump, consisting of parts A-94, A-116, A-118, A-121, A-122, A-124, A-125, A-126, A-127, A-219, A-220, A-221, A-222, two  $\frac{3}{4}''$  steel balls, and four  $\frac{5}{16}'' \times \frac{3}{4}''$  hexagonal-head cap screws. Half section. Scale, select. See Fig. 185 for key to part numbers.

**377-390.** Make a complete set of details of an assigned object from Figs. 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198.

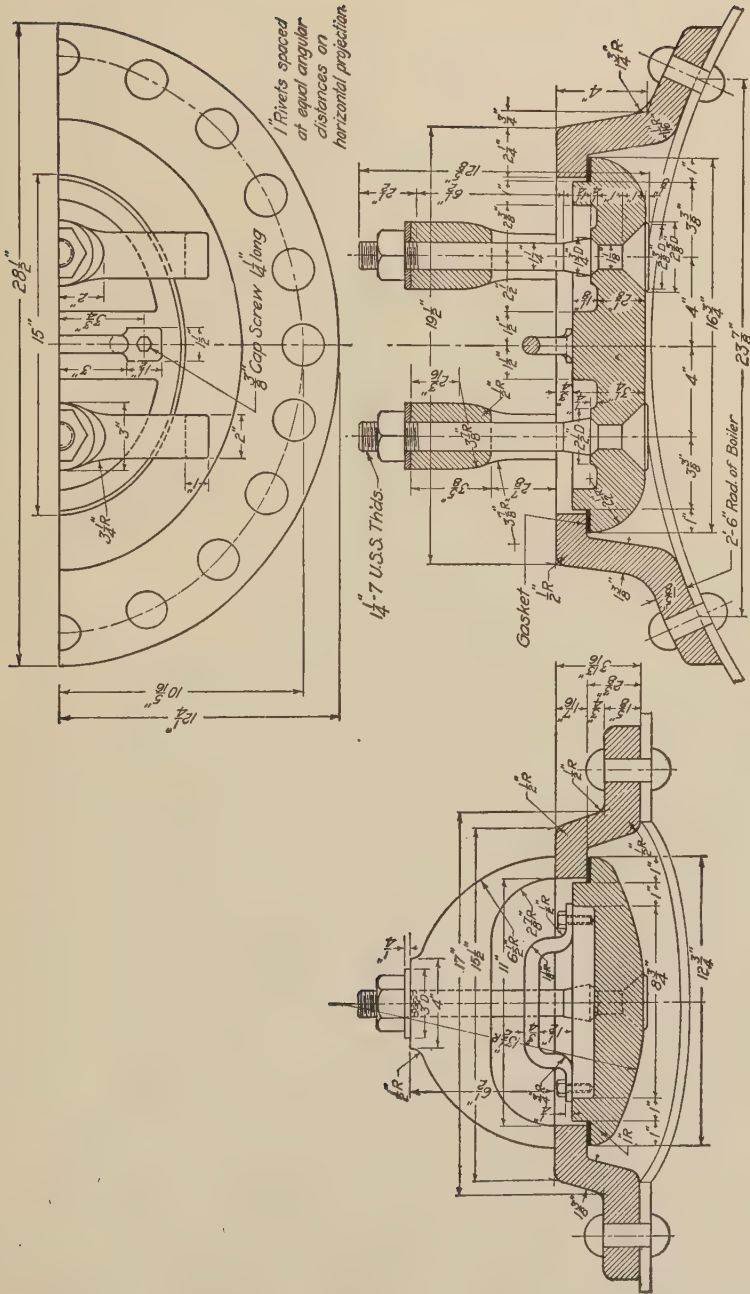


FIG. 196. Manhole.

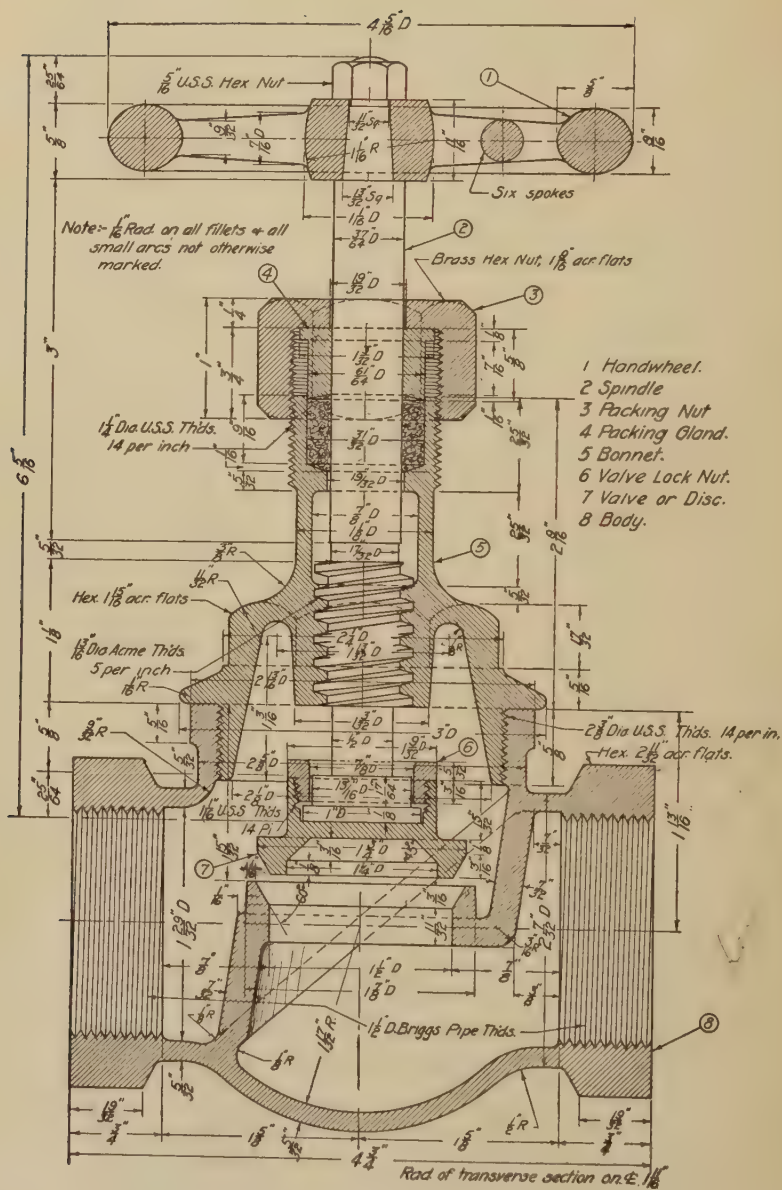


FIG. 197. Globe valve.

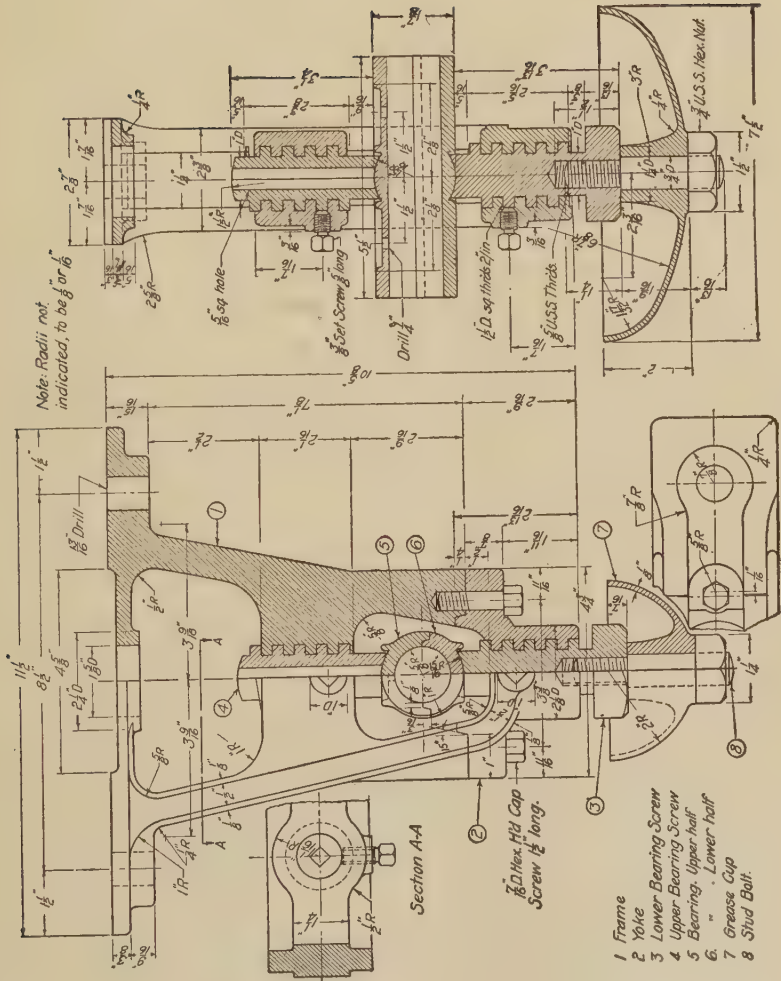


FIG. 198. Shaft hanger.



## ISOMETRIC PROJECTION

Omit dimensions unless directed otherwise by problem or assignment. Show hidden lines only when necessary. Additional problems may be assigned from Figs. 222 to 243.

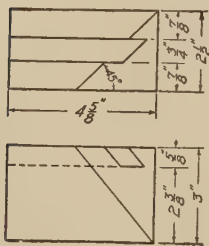


FIG. 199.

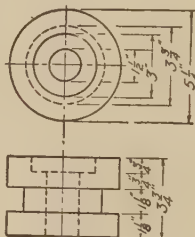


FIG. 200.

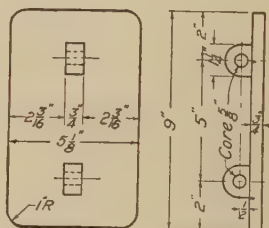


FIG. 201. Beam separator.

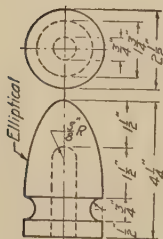


FIG. 202.

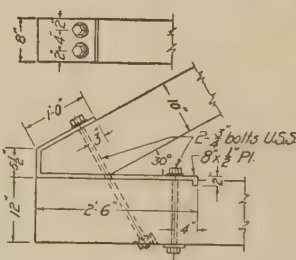


FIG. 203. Truss joint.

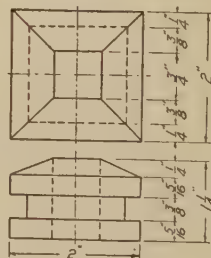


FIG. 204.

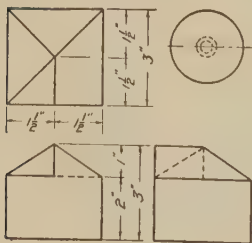


FIG. 205.

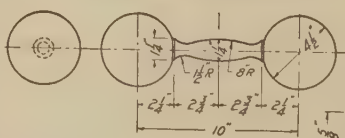


FIG. 206. Dumb-bell.

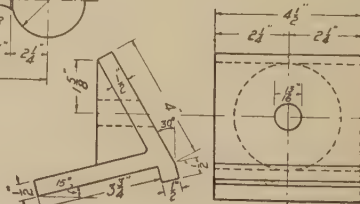


FIG. 207. Truss block.

**391-394.** Make a dimensioned isometric drawing of an assigned object from Figs. 199, 205, 222, 229. Scale  $1'' = 1''$ .

**395-398.** Make a half section dimensioned isometric drawing of an assigned object from Figs. 200, 202, 204, 217. Scale  $1'' = 1''$ .

**399-402.** Make a dimensioned isometric drawing of an assigned object from Figs. 201, 206, 210, 216. Scale  $\frac{3}{4}" = 1"$ .

**403.** Make a dimensioned isometric drawing of the cast iron strut of Fig. 208. Scale  $\frac{1}{4}" = 1"$ .

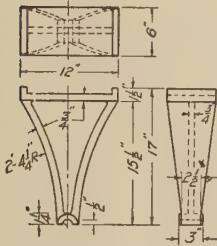


FIG. 208. Strut.

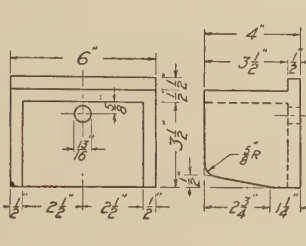


FIG. 209. Beam pedestal.

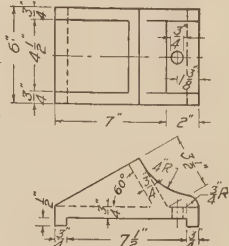


FIG. 210. Truss block.

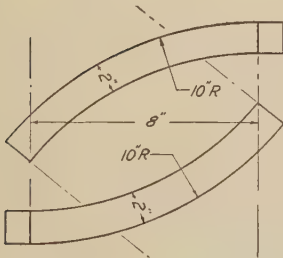


FIG. 211. Balustrade rail.

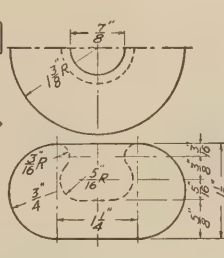


FIG. 212. Knob.

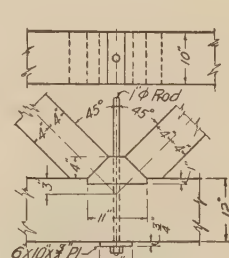


FIG. 213. Truss joint.

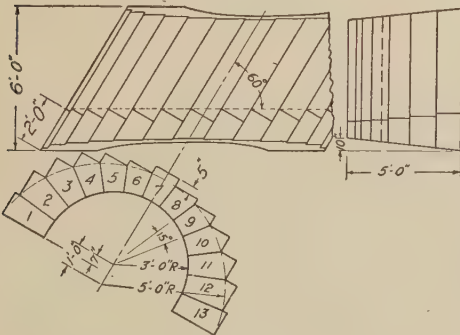


FIG. 214. Skew stone arch.

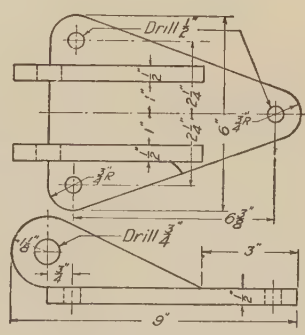


FIG. 215. Hinge.

**404.** Make an isometric drawing of tool box in Fig. 235. Show cover open  $60^\circ$ . Scale  $\frac{1}{4}" = 1"$ .

**405.** Make an isometric drawing of the truss joint shown in Fig. 203. Scale  $1\frac{1}{2}" = 1' - 0"$ .

406. Make an isometric drawing of the truss joint shown in Fig. 213. Scale, select.

407. Make an isometric drawing of the balustrade rail of Fig. 211. Scale  $\frac{1}{2}'' = 1''$ .

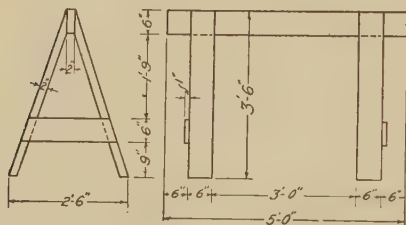


FIG. 216. Carpenter's horse.

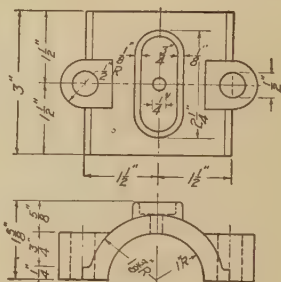


FIG. 217. Bearing cap.

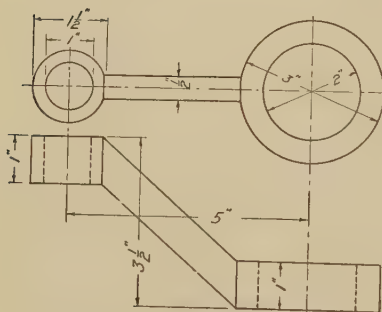


FIG. 218. Angle bracket.

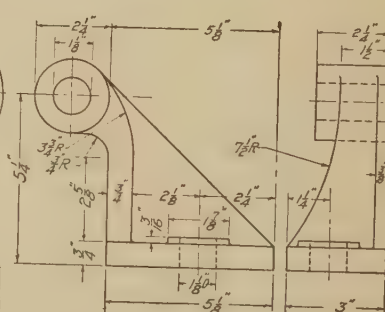


FIG. 219. Bearing bracket.

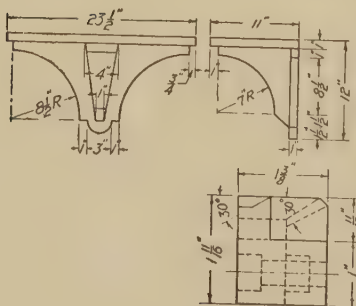


FIG. 220. Shelf bracket.

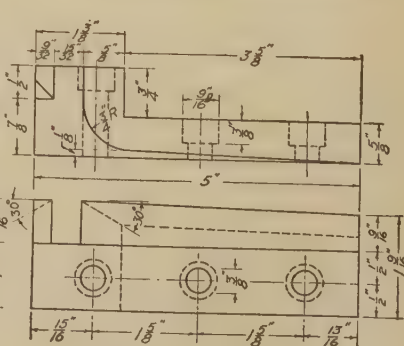


FIG. 221. Shear blade.

408. Make an isometric drawing of the knob of Fig. 213. Scale  $1'' = 1''$ .

409. Make an isometric drawing of an assigned stone in the front face of the arch shown in Fig. 214. Scale, select.

410. Make an isometric drawing of the shelf and bracket of Fig. 220. Scale, select.
411. Make an isometric drawing of the shear blade of Fig. 221. Scale,  $\frac{3}{4}'' = 1''$ .
412. Make an isometric drawing of the elbow of Fig. 231. Scale  $\frac{1}{2}'' = 1''$ .

## SECTION IX

### OBLIQUE PROJECTION

**413-423.** Make a dimensioned or undimensioned cavalier projection of an assigned object from Figs. 222, 223, 224, 225, 227, 228, 230, 231, 233, 241, 242. Select scale.

**424-432.** Make a dimensioned or undimensioned cabinet drawing of an assigned object from Figs. 226, 229, 232, 234, 237, 238, 239, 240 and 243. Select scales.

**433-439.** Make a general dimensioned or undimensioned oblique drawing of an assigned object from Figs. 226 and 236 to 241, inclusive. Select scales.

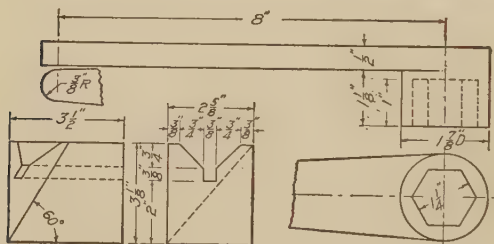


FIG. 222.

FIG. 223. Socket wrench.

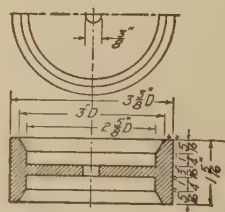


FIG. 224. Pulley blank.

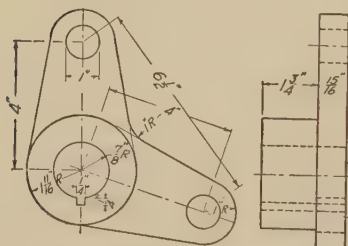


FIG. 225. Rocker arm.

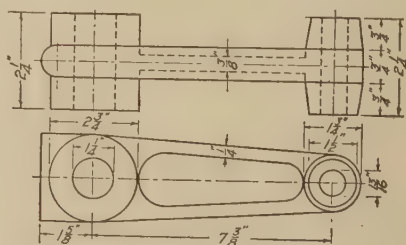


FIG. 226. Connecting rod.

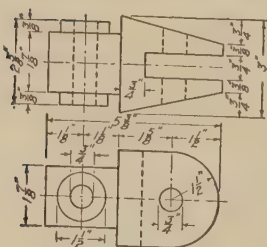


FIG. 227. Link.

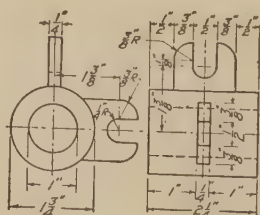


FIG. 228.

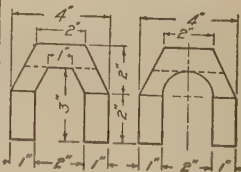


FIG. 229.



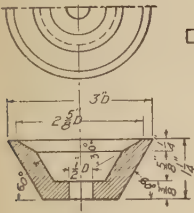


FIG. 230.

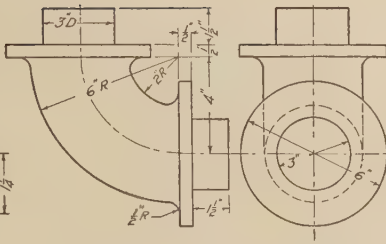


FIG. 231. Elbow pattern.

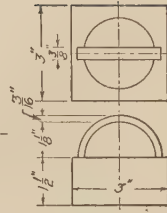


FIG. 232. Dome.

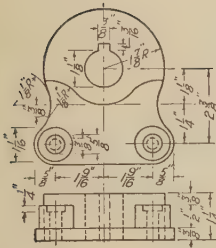


FIG. 233. Cam follower.

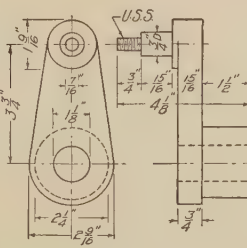


FIG. 234. Crank.

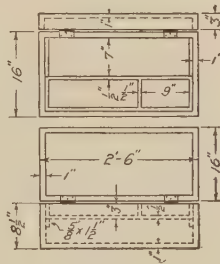


FIG. 235. Tool box.

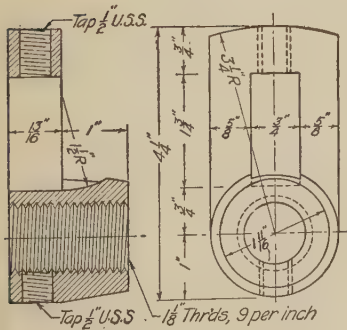


FIG. 236. Cutter head.

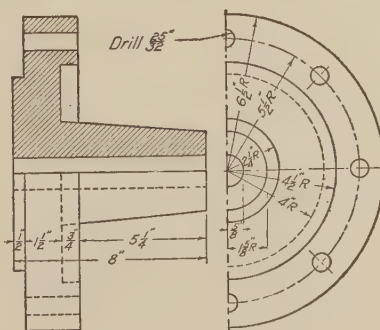


FIG. 237. End plate.

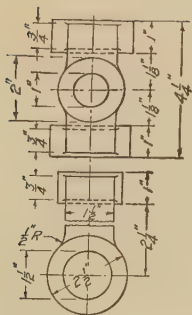


FIG. 238. Swivel yoke.

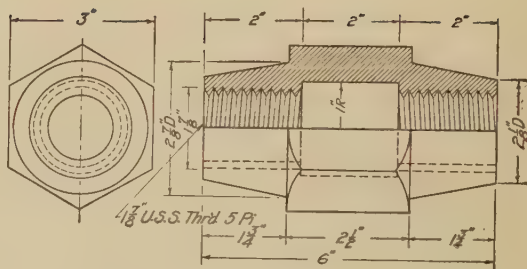


FIG. 239. Sleeve nut.

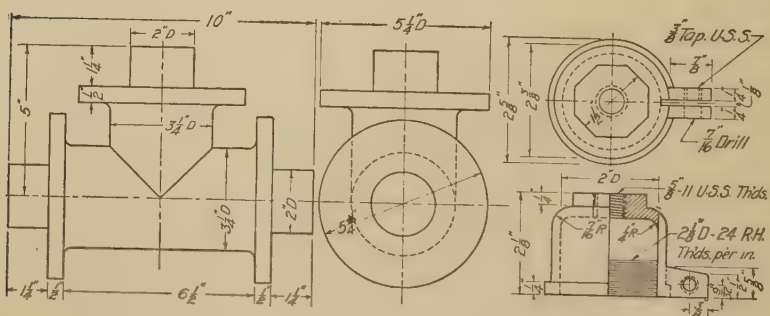


FIG. 240. Tee pattern.

FIG. 241. Wheel puller.

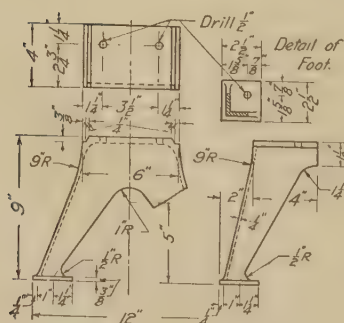


FIG. 242. Lathe leg.

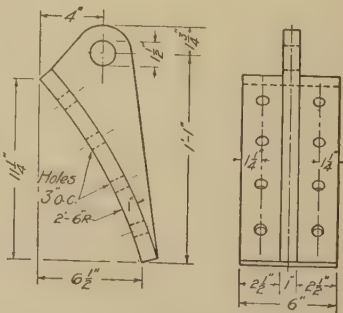


FIG. 243. Boiler hanger.

## SECTION X

### PERSPECTIVE PROJECTION

Although the type of perspective to be used has been specified in each of the problems of this section, and the positions of the picture plane and the point of sight have been worked out to fit the kind of perspective designated, any method may be used with proper adjustment of the two primary factors involved. In angular perspective problems the point of sight should always be directly in front of the vertical edge of the object used in turning it obliquely to the picture plane, that is, the edge nearest the observer. Dimensions should be omitted. New co-ordinate values for the point of sight should be worked out for sizes of paper other than 12"  $\times$  18". The scale specified applies to the point of sight and picture plane dimensions as well as to the object itself in each problem.

**440-454.** Make a parallel (one-point) perspective drawing of an assigned object from Figs. 43, 44, 45, 49, 50, 58, 60, 64, 73, 87, 100, 204, 205, 207, 229. Point of sight is 2" above, 8" in front of, and 4" to the left of the center of the upper face. Picture plane is 1" in front of face nearest to the observer. Scale 1" = 1".

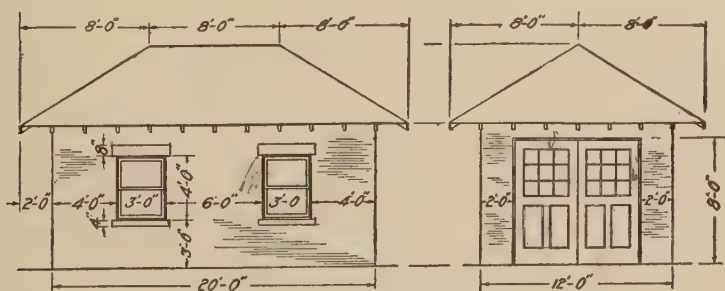


FIG. 244. Single garage.

**455-463.** Make a parallel (one-point) perspective of an assigned object from Figs. 53, 74, 123, 130, 158, 173, 174, 179, 186. Point of sight is 2" above, 8" in front of, and 4" to the right of the center of the upper face. Picture plane is 1" in front of face nearest to the observer. Scale 1" = 1".

**464-468.** Make a parallel (one-point) perspective of an assigned object from Figs. 51, 65, 105, 191, 209. Point of sight is 3" above, 11" in front of, and 5" to the right of the center of the upper face. Picture plane is 1½" in front of face nearest observer. Scale ¾" = 1".

**469-474.** Make a parallel (one-point) perspective of an assigned object from Figs. 54, 110, 116, 161, 168, 190. Point of sight 4" above, 14" in front

of, and 7" to the right of the center of the upper face. Picture plane is in front face. Scale  $\frac{1}{2}'' = 1''$ .

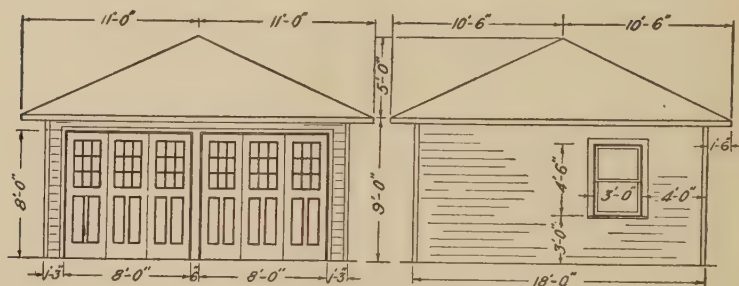


FIG. 245. Double garage.

475. Make an angular (two-point) perspective of the single garage of Fig. 244. Point of sight is 28' in front of picture plane and 6' above the ground. Picture plane is in the front corner of the roof. Front of garage is turned  $30^\circ$  to the picture plane. Scale  $\frac{1}{4}'' = 1' - 0''$ .

476. Make an angular (two-point) perspective of the double garage of Fig. 245. Point of sight is 30' in front of picture plane and 7' above the ground.

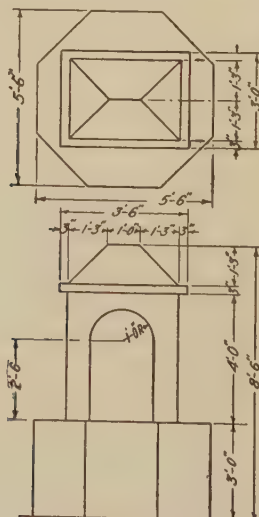


FIG. 246. Memorial fountain.

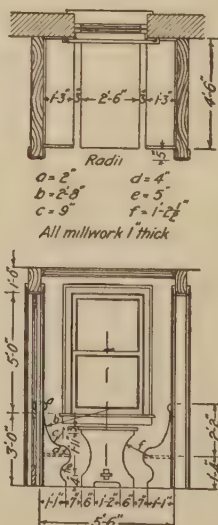


FIG. 247. Breakfast room.

Picture plane is in the front vertical corner line of the building proper. Front of garage is turned  $30^\circ$  to the picture plane. Scale  $\frac{1}{4}'' = 1' - 0''$ .

477. Make a perspective of the memorial fountain of Fig. 246. Point of sight is 16' in front of picture plane, 5' above the ground and 5' to the right of

center plane of the fountain. Picture plane is 1' in front of face nearest the observer. Front face of fountain parallel to the picture plane. Scale  $\frac{1}{2}'' = 1' - 0''$ .

478. Make a parallel (one-point) perspective of the breakfast room of Fig. 247. Point of sight is 10' in front of the picture plane, 2' above and 1' to the left of the center of the table. Picture plane is 9'' in front of table. Scale  $\frac{1}{4}'' = 1' - 0''$ .





## INDEX

---

### A

Abbreviations, 310  
Acme threads, 120, 333  
Aeronautical map symbols, 318  
Alignment chart (see Nomograph), 225  
Allowances, 100  
Alphabet, architectural, 22, 27  
    early Roman type, 22, 25  
    mechanical, 22, 28  
    Modern Roman, 22, 28  
    Old English, 22, 26  
    Old Roman, 22, 24  
Alphabets, compressed and expanded, 17  
    Gothic, 5, 7  
    map, 248  
    modified, 5  
    original, 5  
    Roman, 5  
Angles (see Quadrant), 58  
    deflection, 240  
    standard gage, 336  
Annealing, 134  
Appendix, 301-343  
Appendix, contents of, 299, 300  
Application for patents, 291  
Architect's scale, 43  
Architectural drawing, 251  
    bottom view in, 252  
Architectural drawings, classification of, 252  
Architectural working drawings, 253  
    details, 263  
    dimensioning, 266  
    elevations, 259  
    floor plans, 256  
    lettering, 269  
    notes, 266  
    plot plan, 256  
    sections, 262  
    specifications, 266

Architectural working drawings,  
    symbols, 267  
    technique, 269  
    titles, 269  
Area, diagrams, 220  
    method in lettering, 15  
A. S. M. E. machine screws, 331, 332  
Assembly drawings, 77-80  
Auxiliary lines, 48, 89  
    planes and views, 63-67  
Axes, clinographic, 165  
    coördinate, 208  
    isometric, 151  
    oblique, 158, 163  
    of revolution, 54  
Axonometric projection, 152

### B

Barographs, 217  
    types of, 217-220  
Beams, dimensions of, 336  
Bibliography, architectural, 270  
    charts and diagrams, 228  
    crystallography, 167  
    lettering, 23  
    map drawing, 250  
    perspective, 181  
    structural, 290  
Bill of materials, 96, 290  
Blue line prints, 191  
Blueprint paper, 189  
    intensifier, 189  
    sensitizer, 189  
Blueprint process, 190  
    chemistry of, 190  
Blueprinting, 188  
Blueprinting machines, 192  
Blueprints, use of, 98  
Bolts, carriage, 115  
    conventional drawing of, 124  
    dimensioning, 125  
    stove, 115

- Bolts, stud, 115
    - table of dimensions, 327
  - Boring, 135
  - Bow instruments, 50
  - Briggs pipe threads, 126
  - British standard threads, 118
  - Broaching, 138
  - Broken section, 75
  - Brown prints, 98, 190
  - Butt joint, 128
  - Buttress thread, 119
- C
- Cabinet drawing, 161
    - dimensioning, 162
    - circles in, 161
    - scales in, 161
  - Cadastral maps, 230
  - Cap screws, tables of dimensions, 328-330
  - Capital letters, 6
    - small, 18
  - Carriage bolt, 115
  - Cavalier projection, 156
    - circles in, 159
    - dimensioning, 162
    - distortion in, 160
    - plane figures in, 158
  - Center lines, 48, 88, 96
  - Channels, dimensions of, 335
  - Charts and diagrams, 202
    - classification of, 205
    - Joint Committee rules, 215
  - Charts, alignment, 225
    - distribution, 223
    - logarithmic, 227
    - organization, 224
    - semi-logarithmic, 203
    - three-dimensional, 227
  - Checking a drawing, 94
  - Circles, tangent to lines and circles, 301
    - in isometric, 146
    - in oblique, 159
    - in perspective, 180
  - City plat, 232
  - Civil Engineer's scale, 43
  - Clearance, 272, 283
  - Clinographic projection, 165
  - Compass, 49
  - Composition in lettering, 15
    - principle of balance, 15
    - refinements in, 16
  - Compressed letters, 17
  - Cones, intersections and develop-  
ments, 101, 107
  - Conic sections, 304
  - Contour lines, 243
    - pen, 245
  - Conventional lines, 48, 88
  - Conventional symbols (see Symbols)
  - Coördinate axes, locating and mark-  
ing, 208
  - Coördinate papers, 207
  - Coördinate planes, 55
    - rotation of, 55
  - Coördinates, selection of, 210
  - Cope, 133
  - Core, 131
  - Core box, 132
  - Core prints, 132
  - Counterbore, 135
  - Countersink, 135
  - Cross-section paper, 207
  - Cross-sections (see Sections)
  - Cross-sectioning (hatching), 71
    - metals, 72, 320
    - building materials, 262
  - Crystallography, 165
  - Curve drawing, 212
    - technique, 216
    - titles and legends, 217
  - Curve, irregular (French), 50
  - Curve slope, 211
  - Cycloids, 308
  - Cylinders, intersections and develop-  
ments, 102, 106
- D
- Decimal dimensions, 92
    - equivalents, 339
  - Descriptive Geometry, uses of, 105
  - Design, definition of, 199
    - empirical and technical, 200
  - Detail drawing, architectural, 263
    - machine, 80, 86, 97

- Detail drawing, structural, 276
  - Detail of truss, complete, 282
    - sketch, 275
  - Detailing a truss, 280
  - Details, standard architectural, 267
    - standard structural, 335-337
  - Development of surfaces, 105
  - Developments, cones, 107
    - cylinders, 106
    - outlines of, 109
    - plane surfaces, 108
    - triangle method, 108
  - Diagram, erection, 274, 277
  - Diagrams and charts, 202
  - Diagrams, area, 220
    - graphic statics and vector, 223
    - map and distribution, 223
    - volume, 220
  - Dihedral angles, 58
  - Dimensioning machine drawings, 89
    - architectural working drawings, 266
    - bolts, 125
    - cabinet drawings, 162
    - cavalier projections, 162
    - channels, 335
    - decimal, 92
    - drilled, tapped holes, etc., 92
    - foot and inch sign, omission of, 99
    - freehand sketches, 186
    - I-beams, 336
    - isometrics, 149
    - metric system, 101
    - oblique projections, 162
    - one way, 99
    - rules for, 89-93
    - screws, 125
    - solid line, 99
    - structural shop drawings, 285
    - to finished sizes, 130
  - Dimensions, of beams and channels, 335, 336
    - bolts and nuts, 327
    - cap screws, 328-330
    - machine screws, 331, 332
    - pipe, 325
    - set screws, 333
    - V-threads, 326
    - wire and sheet metal, 334
  - Dimetric projection, 152
  - Directrices, isometric, 143
  - Display drawings, 253
  - Distribution diagrams, 223
  - Dividers, 45
  - Drag, 133
  - Draft on patterns, 131
  - Drawing, a graphical language, 1
    - architectural, 251
    - chart and diagram, 202
    - freehand, 182
    - isometric, 142
    - machine, 2, 86, 97
    - map, 229
    - oblique, 156
    - patent office, 291
    - perspective, 168
    - structural, 271
  - Drawing board, 38
  - Drawing course, purpose of, 36
  - Drawing paper, 41
  - Drawing pencils (see Pencils), 19
  - Drawings, assembly, 77
    - checking and revising, 94
    - detail, 80
    - display, 253
    - for etchings, 195
    - reproduction of, 193
    - working or shop, 76
  - Drills, 134
  - Drill press, 134
  - Drop forging, 133
- E
- Electrical wiring symbols, 319
  - Elevation on maps, 242
  - Elevations, architectural, 259
    - half façade, 262
    - shade lining on, 261
  - Ellipse, construction of, 305
  - Empirical design, elements of, 200
  - Engineer's scale, 43
  - Engineering drawing, divisions of, 2
  - Engineering maps, 230
  - Epicycloid, 308
  - Equivalents, decimal, 339
    - metric, 338
  - Erasers, 38
  - Erasures, 96

Etchings, drawings for, 195  
 Expanded letters, 17  
 Exposure of blueprint, 189

## F

Fasteners, classifications, 114  
 Fillet, material for, 131  
 Fillets, 103  
 Finish, how indicated, 93  
 First-angle projections, 59  
 Fit, push, drive, etc., 100  
 Fittings, pipe, 321-325  
 Fixtures, 137  
 Flange fittings, 322  
 Flask, 133  
 Floor plans, 256  
 Foot and inch signs, omission of, 99  
 Foundry, 133  
 Forge shop, 133  
 Fractional equivalents, 339  
 Fractions, 15  
 Freehand drawing, 2  
 French curve, 50

## G

Gage lines, 279  
 Gages, angles, 337  
     rivet, 335-337  
     sheet and plate metal, 334  
     wire, 334  
 Geographic maps, 229  
 Geometrical constructions, 301  
 Graphic statics diagrams, 223  
 Graphical representations, 204  
 Grinding, 136  
 Guide lines, 12, 13

## H

Hachures, 243  
 Half-sections, 69  
 Half-tones, 197  
 Hectograph, 194  
 Helix, 117  
 Highway map, 232  
 Hyperbola, construction of, 308  
 Hypocycloid, 309

## I

I-beams, dimensions of, 336  
 Ink lines, weight of, 48, 88  
 Inking drawing, 95  
 Inking, order of, 96  
 Instruments, selection of, 45  
     set of, 44  
     quality of, 45  
     use and care of, 36  
 Intensifying a blueprint, 189  
 Interpolated sections, 73  
 Intersections, cone and cylinder, 103  
     of surfaces, 102  
     prism and cylinder, 109  
     prism and sphere, 104  
     two cylinders, 102  
 Invisible lines, orthographic projection, 62  
 Involute, 309  
 Irregular curve, 50  
 Isometric, axis, 143  
     circle and curves in, 146  
     coördinate method, 147  
     definition of, 142  
     dimensioning in, 149  
     drawing, 144  
     plane, 142  
     plane figures in, 145  
     planes of construction, 148  
     point of sight, 142  
     position of axes, 151  
     projection, 142  
     scale, 144  
     threads in, 150  
     sections in, 151

## J

Jigs, 137  
 Joint, layout of, 283  
 Joint, lap and butt, 128

## K

Keys, 128  
 Knuckle thread, 119

## L

Lag screws, 116  
 Lap joint, 128



Lathe, 136  
 Lead of threads, 119  
 Leaders, 90  
 Legends, 96  
 Letters, architectural, 27  
     capital, upper case, or large, 6  
     compressed, 17  
     elements of, 6  
     expanded, 17  
     Gothic, 5  
     normal, 8  
     ovals of, 8  
     Reinhardt, 5  
     Roman, 24, 25, 28  
     small or lower case, 6  
     slant, 7  
     stems of, 7  
     vertical, 7  
     weight of stroke, 10, 20  
     widths of, 10

Lettering, architectural working  
     drawing, 269  
     combination of stem and oval, 9  
     composition, 15  
     direction of strokes, 13  
     guide lines, 12  
     maps, 248  
     map titles, 250  
     numerals, 14  
     pens (see Pens), 19  
     Reinhardt style, 4  
     rule of stability, 10  
     slope guide, 11  
     slope of, 6, 7  
     style of, 4  
     summary of principles, 18  
     triangle, 12  
     unit of measure, 21

Limits, 100

Line diagrams, 217

Line etchings, 195

Line shading, 111

Lines, conventional, 87

    center, 48, 88, 96

    contour, 243

    extension, witness, auxiliary, 89

    invisible, 62

    tangent to curves, 303

    true length of, 101

Lithographic printing, 198

Locknuts, 125

## M

Machine screws, dimensions of, 331,  
     332

Machine shop, 134

Magnesium carbonate, 48

Map, drawing, 229

    lettering, 248

    profiles, 245

    scales, 233

    symbols, 235-239

    titles, 250

Maps, cadastral, 230

    city, 232

    classification of, 229

    diagrams, 223

    geographic, 229

    highway, 232

    railroad, 234

    topographic, 230

Marking, structural drawing, 288

Mechanical drawing, 2

Mechanical letters, 21

Metals, abbreviations for, 310

    section-lining for, 320

Metric conversion tables, 338

Metric equivalents, 338

Metric system, 101

Milling machine, 137

Mold, 133

Mosaic, 253

## N

Nomographs, 225

Notes, machine drawing, 96

    architectural drawing, 266

    structural shop drawing, 287

Numerals, 14

Nuts, conventional drawing of, 124

    dimensions of, 327

    lock, 126

## O

Oblique drawing, advantages of, 164

Oblique projection, 52, 156

- Oblique projection, axes in, 163
    - circles in, 159
    - dimensioning, 162
    - distortion in, 160
    - planes of construction in, 162
    - point of sight, 141
    - scales in, 161
    - sectioning in, 164
    - threads in, 163
    - variations of, 165
  - Order of inking, 96
    - penciling, 85
  - Orthographic projection, 51
    - point of sight, 53
    - position of object, 60
    - principal planes, 55
    - projecting lines, 52
  - Orthographic views, 62
  - Ovals in letters, 8
- P
- Paper, blueprint, 189
    - coördinate or cross-section, 207
    - profile, 248
    - quality of, 41
    - selection of, 81
    - sepia, 190
    - sizes of, 41
    - trade names, 41
    - Van Dyke, 190
  - Parabola, construction of, 307
  - Partial section-lining, 113
  - Parting lines, 131
  - Patent office drawings, 291
    - rules for, 291
    - symbols, 297
  - Pattern, definition of, 130-132
    - draft on, 131
  - Pattern-maker's rule, 130
  - Pattern shop, 130
  - Payzant pen, 19
  - Pens, ball point, Coit ball bearing,
    - fine point, Henry Tank, Leroy
    - tube, Newton, Payzant, perfec-
    - tion, speedball, 19, 20
  - contour, 245
  - Pen guards, 21
    - ruling, 46
  - Pencils, 19
    - grades of, 36
    - how to hold, 37
    - shape of points, 37
  - Penciling, order of, 85
  - Perspective, angular, 176
    - definition of, 168
    - distance points, 180
    - line method, 177
    - measurements in, 179
    - of a point, 171
    - of a solid, 175
    - one-point, 175
    - parallel, 175
    - picture plane, 170
    - plan and elevation views, 178
    - plane figures in, 180
    - point of sight in, 169
    - two point, 176
    - vanishing points, horizontal lines, 172
    - vanishing points, inclined lines, 174
    - visual ray method, 175
  - Photo-lithographic printing, 198
  - Photographic reproduction, 193
  - Pictorial drawings, 139
    - classification of, 141
  - Picture plane, 170
  - Pipe, dimensions of, 325
    - fittings, 322, 323
    - lay-out, 321
    - symbols, 322, 324
    - threads, 126
    - weight of, 325
  - Pitch, of helix, 118
    - of threads, 119
  - Plan view, 54
  - Plane curves, 206
  - Plane of projection, 52
  - Planer, 137
  - Planes, auxiliary, 63
    - coördinate or principal, 55
    - horizontal, vertical, profile, 55
    - isometric, 142
    - section, 67
  - Plans, floor, 256
    - set of, 256
  - Plate metal gages, 334
  - Plotted points, indication of, 210

Plotting map traverse, 239  
 tangent method, 241  
 rectangular coördinate method, 242  
 Poché, 253  
 Point of sight, in perspective, 169  
 in isometric, 142  
 in oblique, 141  
 in orthographic projection, 53  
 Polishing, 136  
 Practical drafting methods, 98  
 Preliminary sketches, 252  
 scale of, 252  
 Prints, blue, 188  
 blue line, 191  
 brown, 190  
 sepia, 190  
 Van Dyke, 190  
 Prisms, intersections and develop-  
 ments of, 102, 109  
 problems, 344-393  
 Profiles, from contour maps, 245  
 highway, 232  
 on curves, 248  
 papers, 248  
 railroad, 247  
 scales used on, 245  
 Projecting lines, 52  
 Projection, axonometric, 152  
 cavalier, 156  
 clinographic, 165  
 defined, 52  
 dimetric, 152  
 isometric, 142  
 oblique, 156  
 orthographic, 52  
 plane of, 53  
 perspective, 52, 168  
 trimetric, 155  
 Protractor, 240

Q

Quadrants (see Angles), 58

R

Railroad map, 234  
 Reamers, 135  
 Rectangular hyperbola, 308

Reflected views, 252  
 Reinhardt letters, 5  
 Rendering in Poché or mosaic, 253  
 Representation of threads, 121  
 Reproduction of drawings, by blue-  
 printing, 98, 188  
 etching, 195  
 lithographing, 198  
 photostat machine, 194  
 Reproducing tracings, 191  
 Revising a drawing, 94  
 Revolution of coördinate planes, 55  
 variations of, 57  
 Revolved sections, 73  
 Rivets, 127  
 size and spacing, 280  
 Rivet gages, 335-337  
 spacing, 335-337  
 stagger, 337  
 Riveted joints, 128, 283  
 Rounded corners, projections of, 104  
 Rule of stability, 10  
 Ruling pen, 46  
 filling, 47  
 nibs, 47  
 sharpening, 47

S

Scales, 42  
 architect's, 43  
 engineer's, 43  
 isometric, 144  
 in oblique drawing, 161  
 map, 233  
 mechanical engineer's, 43  
 selection of, 82  
 shape of, 43  
 structural drawing, 284  
 use of, 44  
 Scenographic projection, 168  
 Screw fittings, 323  
 Screws, classification of, 116  
 cap, dimensions of, 328-330  
 conventional drawing of, 123  
 lag, 116  
 machine, dimensions of, 331, 332  
 set, dimensions of, 333  
 wood, 116

- Section planes and views, 67  
 Sections, architectural drawings, 262  
     broken, 75  
     in isometric, 151  
     interpolated, 73  
     offset, 69  
     quarter, half, full, 69  
     removed views, 74  
     revolved, 73  
     structural drawing, 278  
 Sectional views, 85  
 Section lining, 71  
 Sectioning-lining, metals, 70, 320  
     partial, 113  
 Sectioning cylinders, 71  
 Sectioning, oblique projections, 164  
     odd numbered axes of symmetry, 113  
 Sensitizer, blueprints, 189  
 Sepia, negatives, 191  
 Set of instruments, 44  
 Set screws, dimensions of, 333  
 Shade lining, 109  
 Shapers, 137  
 Sheet metal gages, 334  
 Shop drawings, definition of, 76  
     machine, 76  
     structural, 274  
 Shrinkage, allowance for, 130  
 Sketching, 182  
 Sketch materials, 184  
 Sketch proportioning, 184  
 Sketch stroke, 183  
 Slope of letters, 6  
 Slope of plane curve, 211  
 Slope guide in lettering, 11  
 Specifications, architectural, 266  
     in patent office drawings, 291  
 Spline shaft fittings, 129  
 Spiral of archimedes, 309  
 Springs, symbols for, 320  
 Square threads, 120  
 Stems of letters, 7  
 Stove bolt, 115  
 Structural drawing, 271  
     definition of terms, 271  
     scope of, 273  
 Structural shapes, 279  
 Structural shop drawing, 282  
 Structural shop drawing, bottom  
     view, 276  
     details, 276  
     dimensioning, 285  
     erection diagram, 274, 277  
     gage lines, 279  
     kinds of, 274  
     layout of joint, 283  
     marking, 288  
     notes, 287  
     numbers and location of views, 275  
     rivet size and spacing, 280  
     scales, 284  
     sectional views, 278  
     standard details, 279  
     symbols, 289  
     symmetrical members, 278  
     titles, 288  
 Stress diagram, 274  
 Stud bolt, 115  
 Study methods, 3  
 Sub-titles, 35  
 Surfaces, development of, 105  
     intersection of, 102  
 Symbols and conventions, 311  
 Symbols, aeronautical maps, 318  
     architectural, 267  
     building materials, 262  
     electric wiring, 319  
     heating and ventilating, 324  
     map, 235-239  
     miscellaneous, 320  
     pipe, 322  
     rivet, 289  
     structural shop drawing, 289  
     topographical, 312-317  
  
 T  
 Tables, bolts and nuts, 327  
     cap screws, 328-330  
     decimal equivalents, 339  
     machine screws, 331, 332  
     metric conversion, 338  
     metric equivalents, 338  
     pipe, 325  
     rivet spacing, 335-337  
     set screws, 333  
     trigonometric functions, 340-343

- Tables, V-thread, 326  
    wire and sheet metal, 334  
Tangents to circles and curves, 301  
Technical design, 200  
Tempering, 133  
Third-angle projections, 54-59  
Threads, 117  
    acme, 120, 333  
    Briggs standard, 126  
    British standard or Whitworth, 118  
    buttress, 119  
    conventions, 122  
    cutting, 121  
    forms or profiles of, 118  
    knuckle, 119  
    lead of, 119  
    pipe, 126  
    pitch of, 119  
    representation of, 121  
    right and left, 119, 122  
    sharp V, 118  
    single, double, and triple, 119  
    square, 120  
    terms, 119  
U. S. standard or Sellers, 118  
    worm, 119  
Three-dimensional charts, 227  
Thumb-tacks, 42  
Titles, architectural, 269  
    architectural sub-titles, 269  
    balancing, 33  
    charts and diagrams, 217  
    commercial, 30  
    contents of, 29  
    design of, 30  
    embellishments in, 35  
    finish of, 34  
    location of, 30  
    modern, 35  
    prominence of parts, 33  
    purpose of, 29  
    shape of, 33  
    size of, 31  
    structural shop drawing, 288  
    style of letters in, 31  
    sub-titles, 35  
Title space, selection of, 82  
Title strip, 30, 31  
Topographical drawing, 229  
    maps, 230  
    symbols, 235-239, 312-317  
Tracing, 95  
Tracing cloth, use of, 93  
    powders for, 95  
    preparation for inking, 48, 95  
Tracings, reproducing, 191  
Transparentizing oils, 191  
Traverse, plotting of, 239  
Triangle method in developments, 108  
Triangles, lettering, 12  
    testing of, 41  
    use of, 40  
Trigonometric tables, 340-343  
Trimetric projection, 155  
True length of lines, 101  
T-square, kinds of, 38  
    testing, 39  
    use of, 39  
  
U  
United States Standard threads, 118  
U. S. Standard bolts and nuts, dimensions of, 327  
Use of instruments, 36  
    exercises in, 50  
  
V  
Van Dyke paper, 190  
Vanishing points, 172  
Vector diagrams, 223  
Views, arrangement of, 84  
    auxiliary, 63  
    bottom, rear, 66  
    elevation, plan, profile, 54  
    front, end, top, 54, 55  
    relation to each other, 57  
V-threads, profiles of, 118  
    table of dimensions, 326  
Volume diagrams, 220  
  
W  
Wax process, 197  
Washing a blueprint, 189



Whitworth threads, 118  
Wire gages, 334  
Wood screws, 116  
Working drawings, 76  
    arrangement of views, 84  
    bills of materials, 96  
    dimensioning, 88  
    legends, 96  
    notes, 96

Working drawings, order of pencil-  
    ing, 85  
    scales, 82  
    selection of paper, 81  
    selection of title space, 82

## Z

Zinc etchings, 195





thread D = .6495.P



